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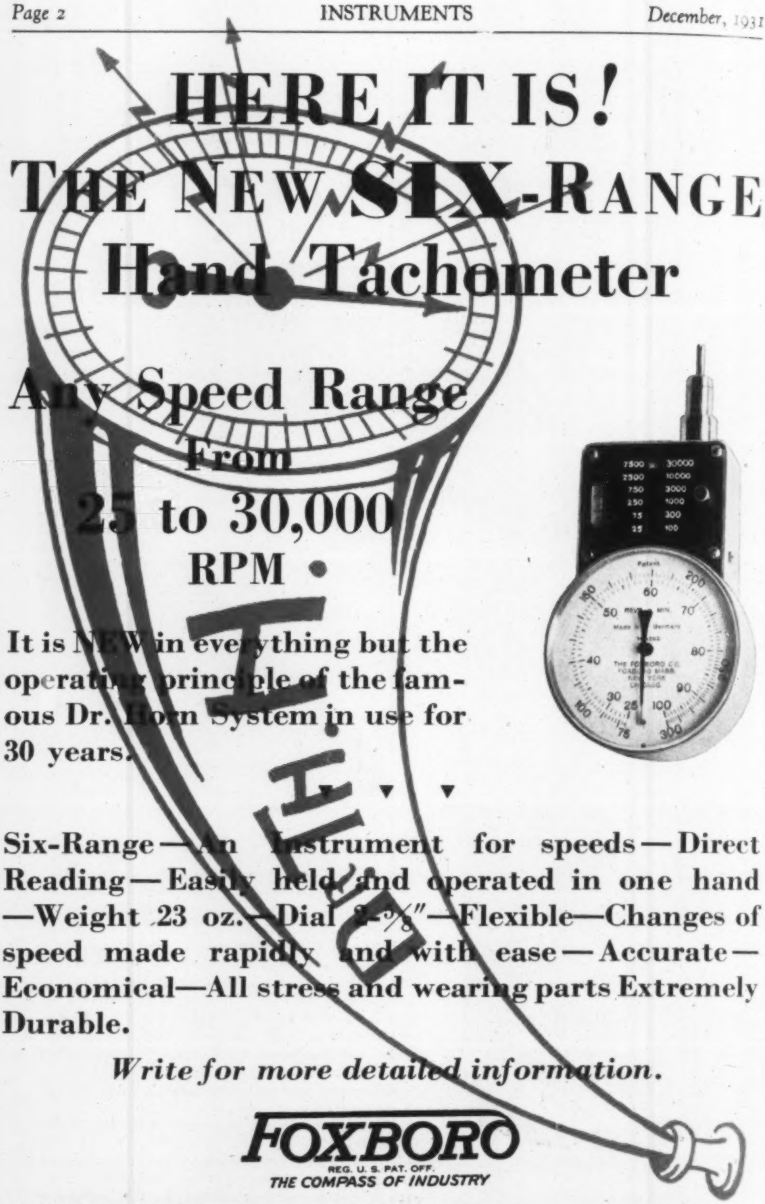
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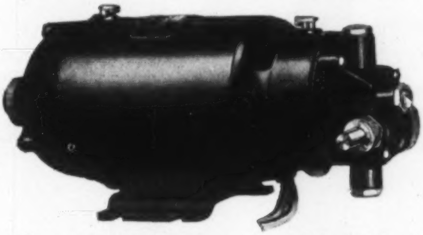

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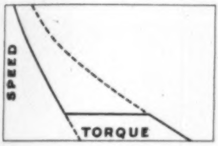

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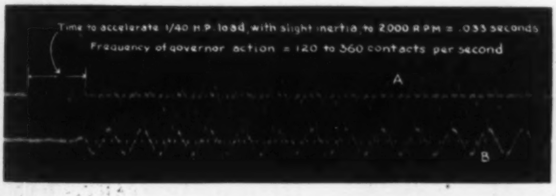

Oscillograms taken on alternating current with electrically governed motor. Oscillogram A is current flowing through governor contacts while voltage across contacts is shown in oscillogram B.

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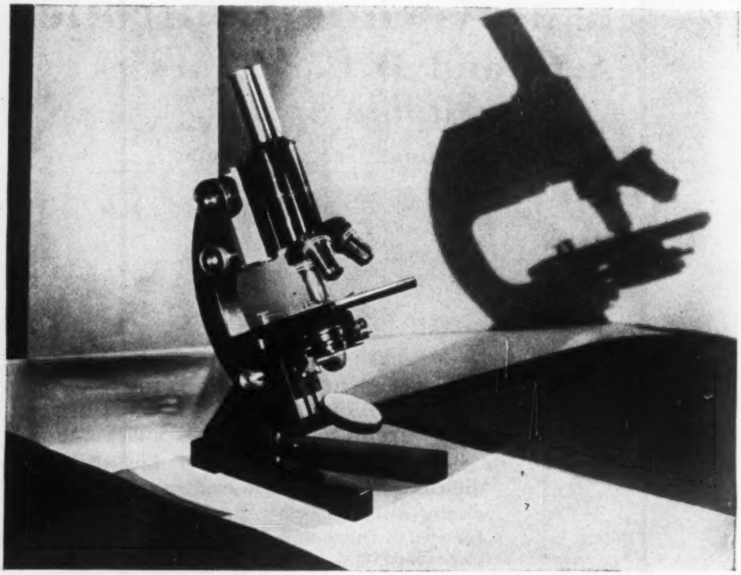

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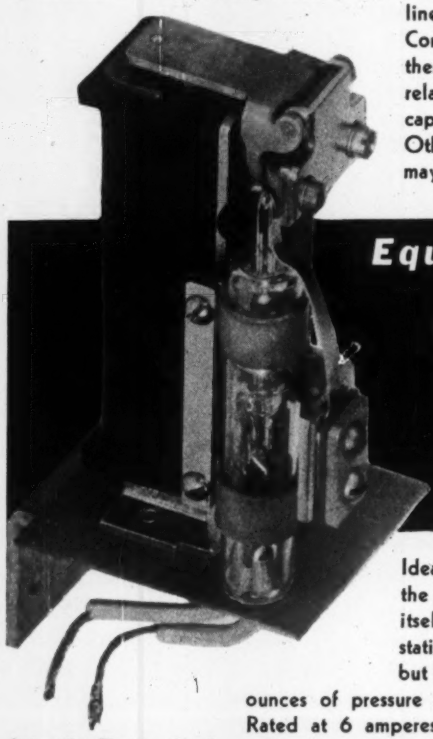

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EDITORIAL COMMENT

"Bigger and . . ."

YOU are now reading the forty-eighth and last "book size" issue of INSTRUMENTS. We go to standard technical journal size beginning with the January issue—slightly under nine by twelve inches overall, with the type pages seven by ten inches. This new format will afford greater scope for convenient arrangement, effective presentation and pleasing appearance, without resorting to trick typography or sensational display.

The larger page size, however, also brings with it a corresponding widening of editorial scope. Or rather, to put it more exactly, the steadily expanding field of measurement and control has created a wider editorial scope for INSTRUMENTS, which is to be reflected in the altered format.

In January, 1928, when the publication was launched, its format was not a matter of chance but the result of a thorough investigation of the field. The editor had determined that the greater need was for the serial publication of authoritative texts and the lesser need was for news items and specific articles. There existed a great deal of information on scientific and industrial instruments and their uses, but it was scattered and inaccessible.

The contents of the new INSTRUMENTS will consist, as at present, of:

1. Original articles on measurement and control problems.
2. Handbooks, published serially.
3. New Instruments Section
4. Current Literature abstracts
5. Buyers' Guide
6. Catalogue Library, listing latest manufacturers' booklets
7. Book Reviews
8. Editorial Comment
9. Help and Situation Wanted notices (inserted gratis)
10. Advertisements

The original articles, for example, will be increased and there will be noticeable a greater departmentizing—reflecting the augmentation and finer organization of editorial activities. In this connection the editor is pleased to announce the accession to the Editorial Board of Mr. H. Olken, who will conduct the department devoted to photoelectric cells and their many uses in measurement and control. Mr. Olken will not only "work behind the scenes" but will contribute original articles. Other members of the Editorial Board will likewise help—both indirectly and directly—to keep our readers in touch with newest developments.

The Manual of Instrumentation

In this issue appears the concluding installment of our Engineering Editor's chapter on speed and acceleration instruments. We originally planned to run his treatise serially, and then issue it in bound form, in one volume The original project has been enlarged. Meanwhile our readers have been requesting the issuance in book form of various sets of chapters. The first book, on temperature and humidity, will be printed in a few weeks and will be followed by others at intervals of a few months, so that Major Béhar's work, when completed, will comprise a set of six or seven handbooks—whence the title Manual for the series which is establishing the foundations of a distinct branch of engineering: Instrumentation.

Measurement of Air Flow

This issue also carries the final installments of Ower's book. Unlike Béhar's Manual, this had been previously published in book form—in England. Struck by the merits of this work, we concluded the necessary arrangements and brought it, through our pages, to thousands of American engineers. It, too, has enjoyed a well-deserved success.

◆

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THE HANDBOOK OF INDUSTRIAL INSTRUMENTS

M. F. Béhar*

CHAPTER XV

Speed and Acceleration

(*Concluded*)

23. Chronographs and Oscillographs

These instruments are not tachometers. Neither are they industrial instruments related to routine production. For certain industrial measurements of speed, however, they are indispensable as auxiliary instruments, their chief value being their ability to provide undistorted graphic records of rapidly changing values. Chronographs and oscillographs usually employ tapes or films providing two or more parallel records one of which is a time scale in smaller divisions than those of the printed charts of the usual forms of industrial recording instruments. Some oscillographs do not furnish permanent records but make it possible to visualize and analyze cyclic effects occurring at frequencies so rapid that ordinary graphic instruments could not record them without distortion.

(a) Chronographs

In the preceding chapter these instruments were discussed with reference to measurements of time. Their use in connection with speed measurements is similar, the method of parallel records being employed. With tapes driven by a motor or by a spring clock work independently of the measured speed, one record is a series of time marks; the other generally corresponds to *motion* or *frequency*, from which speed is then deduced, but it may be a record of instantaneous values of speed, as by means of a suitable rapidly-responsive tachometric element—in which case the chronograph virtually becomes a tachograph.

Of the many forms of chronographs, most are laboratory bench instruments not suitable for industrial work. Some of the chronographs on the market which are of special interest to engineers are the following:

Tape Chronographs. The time-marking element is usually a 100 v.p.s. tuning-fork. For longer intervals external timing devices operate electromagnetic markers. Among these timing devices are chronometers and regulator clocks, some of which are accurate to three seconds per month; also electric time markers operated from small transformers to vibrate with the a-c line frequency; also synchronous electric clocks. The tapes of the Gaertner Scientific Corp. chronographs are driven by universal 110-volt motors, by 12-volt motors, by Warren Telechron motors (for slow paper feeds only), or by spring motors. The paper speed can be regulated on chronographs fitted with universal or with 12-volt motors. On the other hand, when an accurately controlled a-c supply is available, the use of the Telechron motor assures uniform tape speed so that no timing-fork or other timing device is necessary, the time being measurable by means of a millimeter scale.

Drum Chronographs. These instruments resemble the old cylinder phonographs but such a comparison does not flatter the modern models driven by improved driving clocks of ample power and extreme accuracy. Usual drums are 6" in diameter, 11" long and rotate at 1 or 2 r.p.m. At the speed of 1 r.p.m. the second intervals would be marked 8 mm apart by a time-marking pen.

---

*Engineering Editor

The Printing Chronograph. This new instrument is illustrated and described in Sec. 3, Art. (d), of the preceding chapter.

(b) Oscillographs

The Westinghouse Elec. & Mfg. Co. has contributed the following (prepared by A. D. Dovjikov of the Transmission Engineering Dep't) in compliance with our request for a brief but up-to-date classification of all oscillographs with reference to their usefulness in connection with measurements of speed and frequency.

Recording oscillographs may be classified according to the type of phenomena they are designed to record:

1. For slow variations—where period of oscillations is of the order of approximately a second.
2. For oscillations up to the range of audio frequency—approximately 5000 oscillations per second.
3. For extremely fast changes when all phenomena take time measured in micro-seconds.

Graphic meters are available where a visible record of the mechanical movement of the indicator is produced on the moving paper by ink, or by means of electric spark. The comparatively low natural period of oscillation of such a meter and the friction of the pen on the paper may introduce serious error in recording faster transients.

Electromagnetic oscillographs are used where recording is accomplished by a ray of light focused on moving film. The vibrating element has a low natural period of oscillations, but higher than that of graphic instruments by several hundred times. The inertia of the vibrating element is very small and there is no friction between recording element and the film.

For extremely high speed changes, as for instance over voltage on a transmission line during thunderstorms, the natural period of the electromagnetic oscillograph is so low and the inertia is so great it is incapable of responding to such high speed changes, consequently the cathode ray oscillographs are used. The measured magnitude moves the cathode ray which has no inertia and the moving ray makes a record on the photographic plate.

The recording instruments may be classified into two groups:

1. Recording r.m.s. values—graphic meters.
2. Recording instantaneous values—oscillographs.

They may also be classified as follows:

1. Recording steady scale conditions.
2. Automatic recording of transients.

Graphic instruments are usually supplied with a device to accelerate the movement of paper during transients.

Automatic oscillographs for application on power systems, both electromagnetic and cathode ray types, are usually at a standstill and a special device starts recording in case of system disturbance.

For taking record of transients of very short duration the cathode ray oscillograph as well as the electromagnetic oscillograph have corresponding rays available before recording starts.

When disturbance occurs, some effect typical to the disturbance initiates a relay which starts the recording by bringing the ray on the film. The initiating effects are varied. For the cathode ray oscillograph it is usually the overvoltage appearing on the line during thunderstorms. For electromagnetic oscillographs it may be ground or zero sequence current, negative sequence current, positive sequence undervoltage, or any overcurrent or overvoltage.

Further descriptions of oscillographs are omitted from this chapter, being assigned to the electrical handbook part of our manual. Another (and more weighty) reason is that no special oscillographs have been developed for industrial speed measurement purposes, whereas piezometric oscillographs have been developed—and accordingly were described in Part IV, the pressure handbook.

25. Accelerometers

(a) Classifications

Since every force can be equated to mass multiplied by acceleration, it follows that a record of the accelerations of a body also forms a record of the forces causing such accelerations. Acceleration measurements therefore are of value, not only in giving information regarding the changes in the rate at which objects move, and the effect of obstructions, springing devices, etc., but in securing data whereby the forces acting upon the moving body can be calculated.

The usual classification of industrial instruments into indicating, recording and controlling is out of the question here. Automatic control of acceleration is not achieved by control instruments having accelerometers for their primary systems, but by speed-responsive devices. The only accelerometers of practical interest are the measuring instruments. Of these, the instruments for indicating only the instantaneous values of acceleration are of comparatively smaller industrial usefulness, because these values change rapidly. The *recording* accelerometers are the most useful, and this section is devoted mostly to accelerometers that furnish permanent graphic records—of acceleration directly, or of magnitudes from which acceleration may be derived. In addition there are maximum-registering accelerometers which combine simplicity and low cost with considerable practical usefulness to rail transportation and motive power engineers, to aviation engineers, to automotive engineers and service men, and even to non-technical motorists.

By reason of their uses, accelerometers are most conveniently divided into linear and rotational accelerometers. This division also lends itself to descriptive purposes and will be followed in the two descriptive articles of this section.

(b) Methods

When it comes to the principles which may be utilized for instrumental measurement, their number precludes an adequate treatment in the space that can logically be assigned to the subject in this book. Few are of interest to practical industrial men. In general, each one of these principles falls into one of three broad methods involving the measurement of—

(1) Displacement and time (absolute measurement)
(2) Speed and time
(3) Acceleration (direct measurement of effects)

First Method

An exemplification of Method 1 consists in causing a tape to follow the displacement of the object being studied, and in marking this tape at regular time intervals. The combination of a chronographic instrument, as such a frequency Standard causing sparks to be discharged through the tape, together with a linear measuring instrument, then constitutes an apparatus for the measurement of acceleration, but it does not constitute an industrial accelerometer because of the necessity for obtaining the second derivative of displacement with respect to time, which requires the sort of mathematical computation that industrial instruments now tend to render unnecessary. This method, however, is that of absolute measurements and is employed in certain tests where the highest accuracy is desired, or where extremely small time periods are involved.*

A modification of the first method is found in the principle employed by the recording forms of chronometric tachometers (See Section 6). These instruments automatically make an approximate numerical first differentiation of displacement with respect to time, and the record is of successive values of the first derivative, namely speed. These successive values automatically recorded are of *average* speed over the operation period of the instrument, generally one second. This limitation deserves to be discussed at some length.

The accuracy to which the successive values of acceleration can be measured by numerical differentiation varies inversely with the time intervals. This is obvious when one considers, for example, the acceleration of a powerful motor vehicle from rest to a state of uniform motion at high speed Experience is of a pressure by the back cushion against one's back, at first rapidly increasing, then steady and then gradually diminishing to zero. The acceleration *varies* so rapidly that a ten-second measuring period, for example, would be obviously too long. Now, in practically all studies of machinery for which accelerometers are employed, it is desired to obtain knowledge of the maximum value of acceleration—in order to obtain maximum force, maximum strain, etc.—and of the exact time of its occurrence, as well as of mean acceleration and average acceleration, which may differ. Brooks* has demonstrated that only for adequately short measured time intervals will numerical differentiation introduce negligible errors.

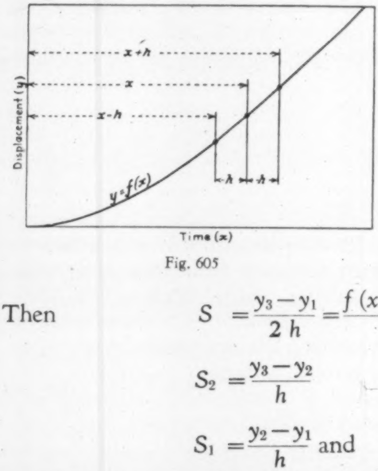

Fig. 605

In Fig. 605, let $y=f(x)$ be the displacement-time curve, and points at abscissæ $x-h$, x, and $x+h$ represent successive measurements, whose values are y_1, y_2, and y_3 respectively.

Let

A = mean acceleration from S_1 to S_2
S = mean speed from $x-h$ to $x+h$
S_1 = mean speed from $x-h$ to x
S_2 = mean speed from x to $x+h$

Then

$$S = \frac{y_3 - y_1}{2h} = \frac{f(x+h) - f(x-h)}{2h} \quad \ldots \quad (1)$$

$$S_2 = \frac{y_3 - y_2}{h}$$

$$S_1 = \frac{y_2 - y_1}{h} \text{ and}$$

---

*See paper on The Influence of Fuel Characteristics on Engine Acceleration, by D. B. Brooks, research associate Bureau of Standards, at June 1926 semi-annual meeting of the S. A. E.

$$A=\frac{y_3-2\,y_2+y_1}{h^2}=\frac{(x+h)-2f(x)+f(x-h)}{h^2} \quad . \quad . \quad . \quad (2)$$

By Taylor's Theorem

$$f(x+h)=f(x)+f_1(x)\,h+\frac{f^{?}(x)\,h_2}{2\,!}+\frac{f_3(x)\,h^3}{3\,!}+\frac{f_4(x)\,h^4}{4\,!}+\frac{f_n(x)\,h_n}{n\,!} \quad . \quad (3)$$

$$f(x-h)=f(x)-f_1(x)h+\frac{f_2(x)\,h^2}{2\,!}-\frac{f_3(x)\,h^3}{3\,!}+\frac{f_4(x)\,h^4}{4\,!}-\ \dots\ +\frac{f_n(x)\,h^n}{n\,!} \quad . \quad (4)$$

Differencing

$$f(x+h)-f(x-h)=2f_1(x)h+\frac{2f_3(x)h^3}{3\,!}+\frac{2f_5(x)\,h^5}{5\,!}+\ \dots\ +\frac{2f_{2+n1}(x)h^{2n+1}}{(2n+1)\,!} \quad (5)$$

Dividing by $2h$ and transposing

$$f_1(x)=\frac{f(x+h)-f(x-h)}{2\,h}-\frac{f_3(x)\,h^2}{3\,!}-\frac{f(x)\,h^4}{5!}-\ \dots\ -\frac{f_{2n+1}(x)\,h^{2n}}{(2n+1)\,!} \quad . \quad . \quad . \quad (6)$$

in which $f_1(x)$ is the true speed at x, $[f(x+h)-f(x-h)]\div 2h$ is the result of numerical differentiation of the data for the mean speed from $x-h$ to $x+h$, as shown in (1) above, and the remaining terms are the difference between the two, and may be used, as desired, either to correct the result of numerical differentiation or to calculate the error thus introduced.

To obtain similar information on acceleration values, (3) and (4) above are added, giving

$$f(x+h)+f(x-h)=2f(x)+\frac{2f_2(x)\,h^2}{2\,!}+\frac{2f_4(x)\,h^4}{4\,!}+\ \dots\ +\frac{2f_{2n}(x)\,h^{2n}}{2n\,!} \quad . \quad (7)$$

Transposing

$$\frac{2f_2(x)\,h^2}{2\,!}=f(x+h)-2f(x)+f(x-h)-\frac{2f_4(x)\,h^4}{4\,!}-\ \dots\ -\frac{2f_{2n}(x)\,h^{2n}}{2n\,!} \quad . \quad (8)$$

Dividing by h^2

$$f_2(x)=\frac{f(x+h)-2f(x)+f(x-h)}{h^2}-\frac{2f_4(x)\,h^2}{4\,!}-\ \dots\ -\frac{2f_{2n}(x)h^{2n-2}}{2n\,!} \quad . \quad . \quad (9)$$

in which $f_2(x)$ is the true acceleration at x, $[f(x+h)-2f(x)+f(x-h)]\div h^2$ is the result of double numerical differentiation for the mean acceleration from S_1 to S_2 as shown in (2) above, and the remaining terms represent the error introduced in obtaining an approximate value for acceleration by double numerical differentiation.

Obviously, decreasing h, the time interval, reduces the inaccuracy of both the speed and the acceleration values obtained. Also the error introduced in acceleration values is a function of the radius of curvature of the acceleration curve, decreasing with increasing radius of curvature. Hence, it is greatest at the point where the acceleration curve changes direction most rapidly. Similarly the greatest error in speed values is introduced when the acceleration is changing in magnitude most rapidly.

Since double numerical differentiation of the cubic is exact, as shown by (9), the error caused by double numerical differentiation in any case is a measure of the departure of the empirical curve from cubic.

To illustrate the magnitude of the error thus introduced, computation was made by Brooks for an acceleration curve similar to that of commercial gasoline. The greatest error which he found to be introduced in the acceleration values, assuming 1 sec. time intervals, was 0.03 r.p.m. per sec.; while the greatest error in speed was found to be 0.6 r.p.m., neither of which is at all serious. As h, the time interval, is reduced, both of these errors rapidly diminish.

Thus for purposes of analyzing the performance of most vehicles while running, the records of one-second chronometric tachometers are generally satisfactory, but when it is necessary to study the changes of speed in the first second after starting from rest, or other transient, the measured time intervals of measured displacements must be correspondingly briefer.

Second Method.

The second method, measurement of speed and time, is approximately realized in tachographs (see Sections 1 and 8) which plot instantaneous speed against time. The accuracy to which such instruments actually record instantaneous and not average speed depends on their dynamic behavior (see Chap. II, Sec. 2). It is the usual characteristic of centrifugal tachographs that they either damp out transient fluctuations and increase the radius of curvature of the acceleration curves obtained from the speed curves or that they overshoot when responding to a rapid change in speed. Now this is exactly what an accelerometer must not do. Acceleration is the rate of change in speed, and an instrument that shows no perceptible error when recording uniform speed but distorts the record when a change in speed occurs will obviously give a speed-time curve which is useless for purposes of differentiation at those very places where one has to get its derivative in order to obtain acceleration. Few regular industrial models of recording tachometers—centrifugal or electric—record transient variations in speed with sufficient sensitivity and accuracy to qualify as accelerometers. They are so damped that their records will be readable at the usual chart speeds of general plant service. Some of them are purposely rendered sluggish so as to make them suitable for application to engines the speed of which varies twice or more during each revolution—depending on the number of cylinders.

There are exceptions, such as, for example, one of the Esterline-Angus electric recorders that has an exceptionally light direct-writing capillary pen and a motor chart drive giving chart speeds of from $\frac{3}{4}$ to 12 inches per second. Such recording tachometers with light direct-writing pens can be depended upon to record without serious dynamic distortion most of the speed variations from which accelerations are computed in many departments of engineering work. We say "without serious *dynamic* distortion" because the pen trace is an arc and hence the strip-chart coordinates are not rectangular, so that only near mid-scale can the speed record be conveniently differentiated for acceleration.

Third Method.

The third method is to measure some effect of acceleration—any effect which is a function of acceleration, and of acceleration only. There are a number of such effects but only a few are conveniently utilizable for purposes of measurement by direct-reading instruments that may be scaled in units of acceleration. These utilizable effects may be divided into three groups: (1) mechanical, (2) electromagnetic, and (3) electrostatic.

Mechanical effects are utilized in the majority of commercial and industrial accelerometers. Some of these instruments will be described in detail and it need only be said here that the application of the principle consists in measuring the deflection of a pendulum—a mass suspended or pivoted with usually one degree of freedom and restrained by an elastic member, by a carefully worked out damping resistance, or by a gravity component.

The deflection is measured in various ways, some of which will be illustrated in the descriptions. (In addition, mention may be made of the electrical methods employed in strain gages, etc., whereby small deflections are indicated and recorded remotely. There seems to be a field for accelerometers made up by combining such instruments.)

As to the electromagnetic and electrostatic effects, accelerometers which utilize them are not being made up and carried in stock by instrument makers. Such instruments will therefore not be included in the illustrated descriptions to follow, and only their principles will now be described:

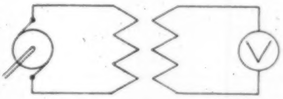

Fig. 606

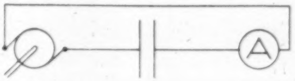

Fig. 607

Both the electromagnetic and the electrostatic direct-measurement principles seem at first glance to be splendidly applicable to utilization in remote-reading industrial instruments, since they both require as the primary element a tachometer magneto.

The former is shown diagramatically in Fig. 606; the latter in Fig. 607. In the electromagnetic accelerometer the voltmeter connected to the secondary winding of the transformer reads zero so long as the magneto speed remains uniform; likewise in the electrostatic set-up, the ammeter reads zero so long as the magneto speed remains uniform.

The electromagnetic method, Fig. 606, makes use of a transformer with a large air gap. The lines of force being proportional to the voltage of the magneto generator and hence to speed, the voltage induced in the secondary winding is proportional to $\frac{d\mathcal{N}}{dt}$, hence to $\frac{d\omega}{dt}$ which is acceleration, but the secondary emf's that can be obtained are too small to operate an ordinary graphic meter; however an oscillograph should give excellent results. Keinath* gives an example of the application of this principle to the measurement of the negative acceleration of emergency braking and shows that the maximum deceleration will only produce 0.144 volt. His data are, *i.e.*, a train coming to a stop in 14 sec. from 100 km./hr.; 50 sq. cm. iron magnet section of magneto; flux density 2000 gauss/cm^2 whence $\mathcal{N}$ = 100,000 maxwells and decrease in 1 sec. = 7200 lines; secondary W_2 = 2000. Then

$$e_2 = \pm \frac{d\mathcal{N}}{dt} K = 7200 \times 2000 \times 10^{-8} = 0.144 \text{ volts.}$$

A serious objection is that on suddenly disconnecting or connecting while running, the induced voltage would damage the measuring instrument.

A somewhat similar application of measuring the electromagnetic effect of acceleration is to supply the tachometer magneto voltage to a moving coil instrument provided wfth a secondary winding connected to a second moving coil instrument or to an oscillograph.

Fig. 607 shows the set-up for measuring acceleration by electrostatic effect and the following discussion is abstracted from the third edition of Keinath: A d-c magneto with as high voltage as possible is driven by the measured shaft and is connected over a condenser C, an ammeter *Ic*, to the unavoidable resistance *R* in which the armature resistance is also to be included, so that in the formulas *R* includes not only the ohmic value of

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*Die Technik Elektrischer Messgerate, Third edition, Berlin, 1928, page 323.

R proper but also the ohmic resistance value of the armature. To each change of speed corresponds a change in voltage which sends a current impulse, proportional to acceleration, through the measuring instrument. The voltages in the circuit are

$$E = \epsilon \ + \epsilon \ = iR + \frac{1}{c}\int idt$$

from which it follows that

$$C\,\frac{d\epsilon}{dt} = i + CR\,\frac{di}{dt}$$

which finally gives current as

$$i = kC\frac{d\omega}{dt} - kC\,\frac{d\omega}{dt} \times l^{-\frac{}{\mathrm{Rc}}}$$

$\frac{d\omega}{dt}$ is the required acceleration. The second member is the correction due to ohmic resistance R. If this equals 0, the charge of the condenser would follow the voltage in infinitely small time value t. The larger the resistance value for a given value of capacity, the slower will the charge follow the voltage. With very fast changing speed, that is, at large accelerations, errors can occur. For $e = 800$ V, $n = 2000$ r.p.m., $R = 1000$ ohms and $C = 40$ mfd, the error after 0.2 seconds is only 1%, but larger errors are caused by the mechanical inertia of the recording device which lags from 0.5 to 1.0 sec. (depending upon the weight of moving system) behind the current when a change takes place. If the magneto generator develops a voltage of 800 at maximum speed and $C = 40$ mfd, then for a 14-second period emergency braking (as above),

$$i_c = C\frac{dE}{dt} = 40 \times 10^{-6} \times \frac{800}{14} = 2.28 \text{ milliamps.}$$

Since the resistance of the measuring instrument can be rather high—up to 1000 ohms—without causing appreciable errors, it follows that a rugged instrument must be used with small natural period (light weight moving element). A disturbing factor in this method is dielectric hysteresis, and condenser leaking (which would require a good mica condenser).

COMMERCIAL ACCELEROMETERS

(c) Linear Accelerometers

"*Ball-and-Ramp.*" In recent years motorists have seen around brake service stations a surprisingly simple form of registering accelerometer consisting essentially of an inclined plane up which a ball travels "by its own inertia" when the device is accelerated in the opposite direction. This device is used to give rough but useful yes-or-no indications (not however true measurements) as to braking efficiency or, conversely, as to "pick-up."

This class of devices represents an adaptation of Galileo's experiment performed in elementary physics classrooms with a marble rolling down an inclined plane under the influence of the gravity component parallel to the inclined plane. The similarity is not immediately apparent because the acceleration of the marble is oblique—so that at first glance it is not a case of exactly reversing the Galileo demonstration. Whence heated discussions—generally inconclusive—wherever the calibration of one of the devices is questioned, partisans of one side maintaining that whereas the *marble* travels over space S, Fig. 608, the *car* only travels over distance D (relative to the marble). That this has nothing to do with the case may be shown in several ways, all of which bear interestingly on the theory of calibrating inertial accelerometers.

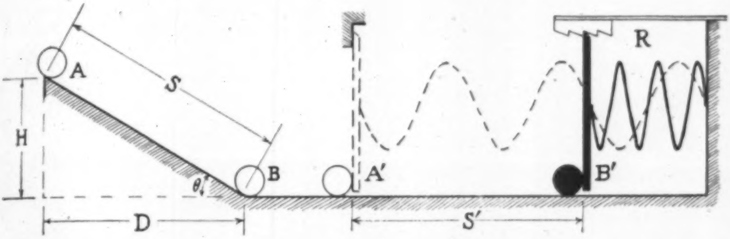


Fig. 608

A rigorous mathematical analysis of the instantaneous velocities—relative to the car and to the ground—during the ascent resembles the problem of the curve down which a ball will roll in the shortest time (calculus of variations); but is is unnecessary, we believe, in view of the proof furnished in Fig. 608. Galileo's marble rolls from A to B through space S in time t and acquires velocity v. It proceeds horizontally at v until it encounters an ideal inertialess and frictionless arrangement R, of which the perfectly elastic spring has an absolutely constant tension. It then is uniformly retarded and comes to rest after traveling from A′ to B′ over space S′ in time t. The arrangement R is held by a sear notch in the position shown by the solid lines. The acceleration a of the marble from A to B was v/t or $2S/t^2$; its acceleration from A′ to B′ is likewise $v/t = 2S/t^2 = a$. When the sear is released, the marble starts from rest at B′ with acceleration a, travels at increasing velocity to A′, rolls horizontally at uniform velocity v, and travels from B to A where it comes to rest. In all four cases of accelerated motion, the value of the acceleration was a. Now repeat the second half of the procedure but instead of releasing the sear, move the entire frame of the apparatus toward the right with acceleration a, let it cover space S in time t and then continue moving toward the right at velocity v. What happens to the marble is obvious: it first remains stationary with respect to the earth, and therefore, with respect to apparatus; it starts from rest at B′ with uniform acceleration a, travels from A′ to B at v (with respect to apparatus) and climbs in time t from B to A where it comes to rest with respect to apparatus, moving now at v with respect to the earth.

Repeat again but let the starting conditions be the entire apparatus with marble at B′ moving toward the *left* at *any* uniform velocity v' greater than v. Now "apply the brakes," causing negative acceleration a. At the end of time t the velocity will be $v' - at = v' - v$, and the marble will be crossing point A′. At that moment, "release the brakes." The marble will travel from A′ to B at v with respect to the device, will climb the incline, and, at the top, will come to rest with respect to apparatus.

In terms of gravity, $a = g \sin \theta$. In Fig. 608 $\theta = 30°$, hence $a = g/2$ or 193.2 in. per sec. per sec. By substituting in the laws of falling bodies, the length S in inches can be determined for any desired value of t in hundredths of seconds. Also, in actual tests of brakes or pick-up, whenever the acceleration is greater than ½ g, the ball of a brake-testing device with a 30° incline will *start from rest* at the foot of the incline, since the acceleration component will more than neutralize the gravity component. The ball will be accelerated by the differential acceleration and when this differential is small, the motion of the ball is slow enough to be followed with the eye. Example, when the differential is 1 in. per sec. per sec. the ball will take 3 sec. to reach the top of a 4-1/2 in. incline.

Since in actual tests, the duration of braking and pick-up impulses should always be several seconds, the devices are usually made with an incline several inches long. The slope varies The computed or actually calibrated corresponding values of car acceleration are printed on the device.

For cases of variable accelerations, the computations, as mentioned above, involve mathematics beyond the scope of what is meant to be a practical discussion, but we may give one more example. With the same device, having a 30° incline 4½ in. long, an application of the brakes powerful enough to equal 2 g need only last long enough to cause the ball (starting from rest at the foot of the slope) to travel just beyond half way up with uniformly accelerated velocity, for it will cover the other half against the gravity component even if the car's speed is then uniform. The duration of this impulse need only be slightly greater than $\sqrt{2 \times 2\frac{1}{4}/193.2}$ which is approx. 0.152 sec.

Therefore, such devices register not only average accelerations but momentary effects due to rough road surface, etc. In using them, one should make certain that no disturbing factors caused an apparently successful registration. It is best to repeat each test several times on a smooth and level road.

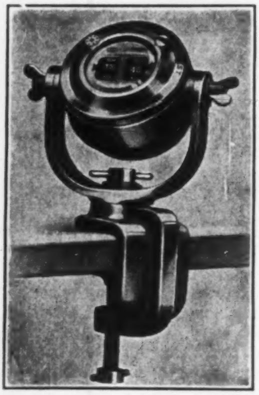
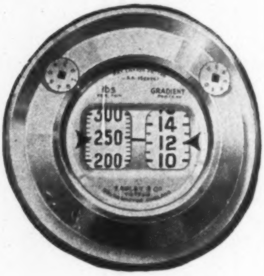


Fig. 609

Fig. 610



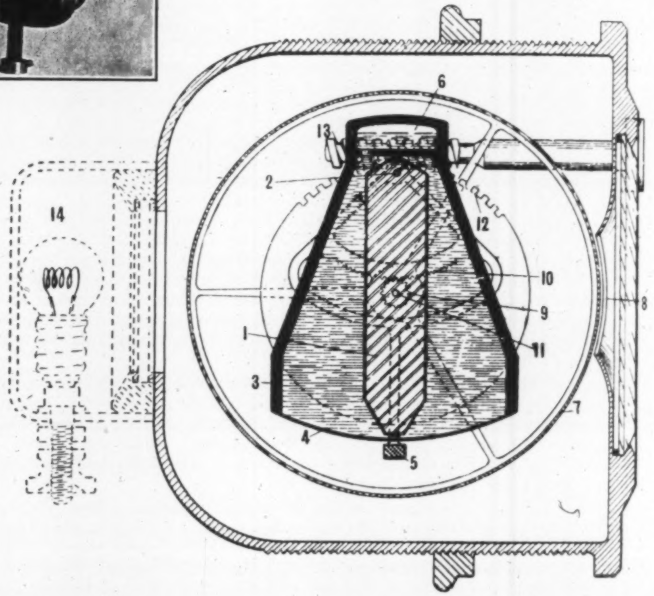


Fig. 611

The Tapley Gradient and Performance Meter. This is a British device (Burton-Rogers Co., U. S. Agents) capable of truly *measuring* accelerations of vehicles not only on level roads but on grades. Figs. 609 and 610 show the general appearance and Fig. 611 is a sectional drawing in connection with which the makers have supplied the following description:

The main controlling pendulum shown at 1 is suspended on centers at 2, so that it is free to take up a vertical position. It is obvious that when mounted on a moving car, such a pendulum, if uncontrolled, would be caused to sway about in an erratic manner by every jolt, so that no useful indication could be obtained from its movements. A feature of the Tapley Meter is the method which has been adopted to overcome such erratic oscillation. The pendulum, which consists of a powerful permanent magnet, is enclosed in the box 3, and the latter is completely filled with a suitable damping fluid, and is hermetically sealed.

The fluid so steadies the movements of the pendulum that while it remains free to retain its vertical position, it is entirely unaffected by any sudden shock or jar to which the instrument may be subjected, and the constant oscillation that would take place with an undamped pendulum is suppressed.

A very thin curved copper plate, 4, forms the bottom of the box, and outside the box on centers, which are in line with the inner centers, is supported a light armature, 5, so arranged that by magnetic attraction from the steadied magnetic pendulum it will indicate the exact position in which the pendulum lies.

By means of a geared segment and pinion, the movements of the armature are transferred to the revolving indicating scale, 7. The latter encircles the damping box and is seen through the window, 8, in the face of the instrument. Thus, although there is no mechanical connection with the controlling pendulum, the relative position of the latter is registered by a dead beat movement of the scale to a figure representing the gradient.

In Fig. 611 the instrument is shown with its face vertical; it will be apparent, however, that the face may be set at any angle and by means of the worm and worm wheel shown at 13 and 12, the whole mechanism can be turned in relation to the faceplate so that the indication can be correctly set at level when the meter is mounted in a sloping position.

In order to eliminate entirely the effects of jolting under exceptionally rough road conditions the spindle of the revolving scale is provided with a light adjustable frictional damping, which can be brought into action when desired.

The indications may be illuminated, by means of the electric light attachment, 14, the light shining through the scale.

Space limitations prevent reprinting the explanation of this instrument's calibration as given in an interesting 28-page booklet. The general principle is that when the instrument indicates, say, a grade of 1 in 10, the vehicle is either at rest (or in uniform motion) on a grade of 1 in 10, or—and here is the main point—if on a level road it is being accelerated by a force equal to one-tenth of the weight of the vehicle. Also, the car may be being subjected to an acceleration of one-twentieth of its weight while traveling down a grade of 1 in 20. Conversion tables and other data are supplied to users. The American agents have also published instructions from which the following extract is particularly illuminating:

1. Maximum pulling power test: Drive in high gear up any hill sufficiently steep to keep the speed low. With the accelerator fully depressed, note the maximum pounds pull reading of the Tapley Meter (which comes just before shifting to second gear is necessary).

2. Acceleration pull and carburetor adjustment test: Drive on a level road at the lowest speed from which the car will accelerate smoothly (about 10 miles per hour). Depress the accelerator fully, and as the car speeds up note the maximum pounds pull reading (which will appear about when the car reaches 25 miles per hour). This acceleration pounds pull should be within 10% of the maximum pounds pull as obtained in test No. 1, provided the carburetor is correctly adjusted (assuming the carburetor is an efficient one).

Cambridge Recording Accelerometers. These are also pendulum instruments of British manufacture (Cambridge Instrument Co., N. Y., U. S. agents) but their ability to record rapid variations widens their applicability and puts them in the class of engineering instruments.

The standard pattern Cambridge Accelerometer, Fig. 612, can be used for recording either horizontal or vertical accelerations, depending upon the position in which it is placed relative to the direction of the movement being investigated. A plan of the instrument, as placed for recording vertical accelerations, is shown diagrammatically in Fig. 613. The mass *M* is supported by two flat steel strips, *H* and H_1, and is connected by means of an additional steel strip *N* to a member *O* moving on knife edges *K* and K_1. This member carries a flat strip of aluminum *L*, one end of which is free to move between the poles of a magnet *P*. Fixed to the aluminum strip *L* is the stylus *Q*. Any movement, therefore, of the mass moves the stylus across the celluloid film *A* which is caused to pass round the roller *T* by means of clockwork mechanism not shown in the diagram. The speed of travel of the film may be varied from approximately 3 to 20 mm. per second.

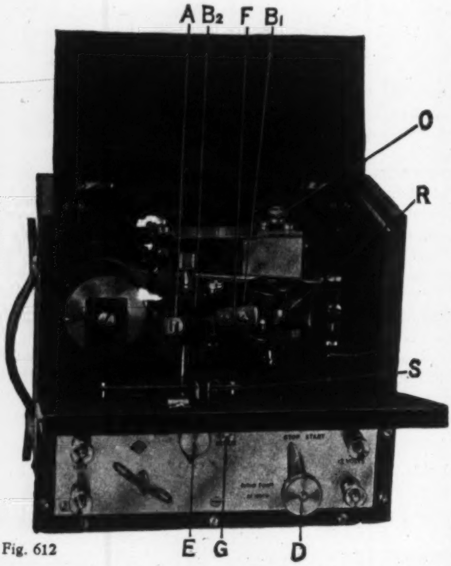


Fig. 612

The eddy currents set up by the movement of the aluminum strip between the poles of the magnet critically damp the movement. With the standard spring, the natural period of the whole system is approximately 0.025 second. With this period the sensitivity is approximately 1 mm. on the actual record for an acceleration equal to g, i.e., 32.2 ft. per sec. per sec. (981 cm. per sec. per sec.); the record can be measured to an accuracy of one hundredth of this value. Other sensitivities can be quickly obtained by substituting suitable control springs, the period being correspondingly altered. The pressure of the stylus on the film can be varied by means of the screw C. An electromagnetic marking mechanism, not shown in the diagram, is fitted so that a time scale, generally tenths of a second, can be marked on the film by means of an additional stylus operating on the back of the film. It is thus possible for the stylus making the record of accelerations to pass over the whole of its range without fouling the time-marking stylus. Alternatively, the second stylus may be arranged to give records of the instantaneous positions of the moving object, or other datum marks.

The complete mechanism is enclosed within a compact case, fitted with two hinged lids (see Fig. 612). On the front of the case are carried the various switches for controlling the mechanism, together with the terminals for connection to the time-marker and to the 12-volt battery for the damping electromagnet. The clockwork mechanism is started or stopped by rotating the switch *D*, but it can also be started independently by depressing the push

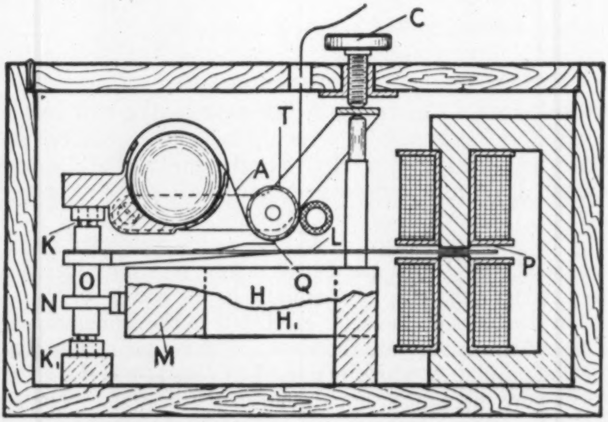


Fig. 613

button G when it is only desired to run a short length of film for calibrating purposes. The records may be easily calibrated by running the film with the instrument set first on its long base and then on its short base, or vice versa, pressing the button G for a second in each position. This operation gives a definite "step" in the record, the height of which represents the acceleration g due to gravity. The speed of the film is adjusted by means of the regulator lever *E*. The instrument may be placed on either its long base, for recording vertical accelerations, or its short base, for recording horizontal accelerations.

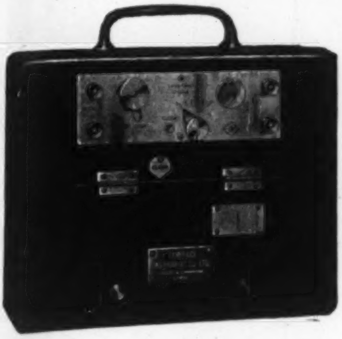


Fig. 614

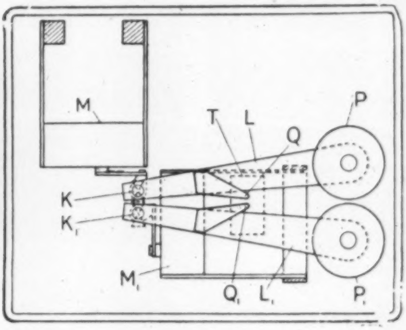


Fig. 615

For some purposes it is convenient to have a record of the accelerations in two planes at right angles, *e.g.*, to obtain simultaneous records of horizontal and vertical accelerations, or, alternatively, accelerations in two directions at right angles in a horizontal plane. The Cambridge instrument shown in Figs. 614 and 615 has been designed to meet this requirement. It is of similar design to the single accelerometer, Fig. 612, but is fitted with two weights, M, M_1 (Fig. 615) mounted on flat steel strips, so that they can only move in planes at right angles to each other. Movements of the weights relative to the instrument are transmitted to two styles, $\mathfrak{Q}$, $\mathfrak{Q}_1$, situated side by side, and moving over the celluloid film in a similar way to that already described, both movements being critically damped by means of the electromagnets P and P_1. Time or other datum lines are marked by means of a third stylus operating on the back of the film.

The records made by the Cambridge accelerometers are of small dimensions, and are permanent. The lines forming a diagram are clearly defined, and will bear considerable magnification. They can be examined at once by means of a suitable microscope, or direct enlargements can be obtained by photographic methods, by a camera lucida, or by projection upon a screen and tracing. Each record consists of a fine black line enclosed between two white lines; this triple line is due to an optical effect produced by the indentation of the celluloid surface by the spherical point of the stylus. It enables any point on the enlarged diagram to be read with greater precision than is possible when examining purely photographic records obtained in the usual manner.

From the manipulative point of view, the small celluloid record has advantages over records taken on a photographic film, or paper. The records can be cut from the celluloid strip and examined immediately after they are made, without chemical treatment or the use of a dark room. There is thus a saving in time, and the danger of spoiled records due to premature exposure or imperfect development is eliminated. The records are durable and are capable of withstanding the worst conditivns of dirt and wet without special handling precautions. The length of celluloid strip provided is sufficient for the production of a large number of records. Figs. 616, 617, 619 and 620 show typical records.

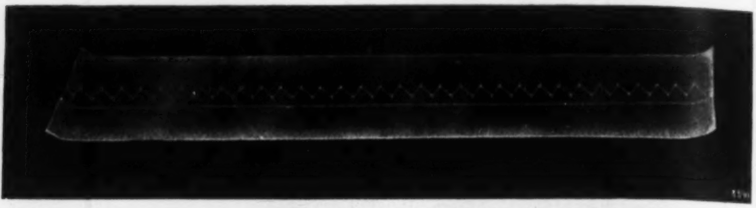


Fig. 616. Reproduction (actual size) of an accelerometer record obtained on the ram of a shaping machine with quick return motion. The "ripples" are due to imperfectly formed teeth in the driving gears. (*Cambridge Instrument Co.*)

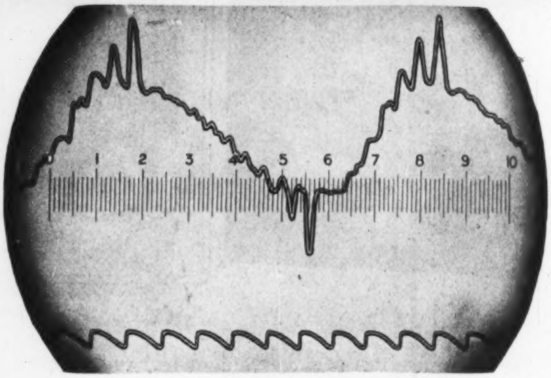


Fig. 617. A portion of Fig. 616 as viewed through the microscope which is accessory to accelerometers. (*Cambridge Instrument Co.*)

(d) Rotational Accelerometers

Cambridge Rotational Accelerometer. This instrument records angular variations about a state of steady rotation, or variations in the angular velocity of rotating bodies. It can be used for tracing and measuring cyclic fluctuations and other variations in the speed of internal combustion engines and electrical machinery, as well as for measuring the comparatively steady angular accelerations in an electric motor, or other machine, in starting from rest. The torsional resonances in any class of prime mover or driven machinery can be detected and their effects investigated.

A light pulley wheel is driven from the apparatus to be investigated and follows the variations in angular velocity of the latter. It is also spring coupled to a heavy flywheel, the rotational inertia of which is sufficiently high to render its angular velocity sensibly constant. The drive from the pulley to the flywheel is transmitted through a form of linkage so arranged that the relative angular movement between the pulley and flywheel is transformed into a longitudinal movement, which is recorded by a stylus-on-celluloid strip. Fig. 618 shows the instrument with its cover removed and the two-stepped rim of the driving pulley unscrewed from the disk *A*. The driving torque is transmitted from *A* to the heavy flywheel *B* through a light bar which is connected to *A* and to *B* by flexible metal strips. The driving pulley is fixed to the shaft, while the flywheel and the ring carrying the bar are both mounted on a sleeve which is free to rotate on the shaft. The bar is fixed to a spindle inside the shaft, so that any relative angular movement between *A* and *B* will cause longitudinal movement of the bar and hence of the spindle which is in connection with the stylus arm. The drum and celluloid strip are situated at *C*, the recording arrangements being as in the Cambridge linear accelerometers described above.

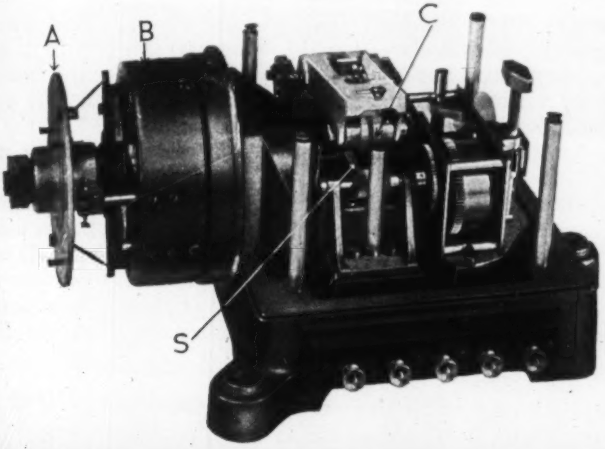


Fig. 618

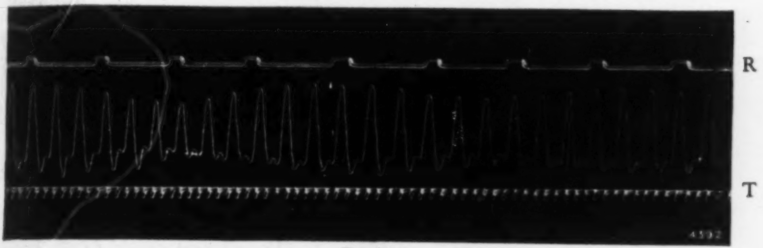


Fig. 619

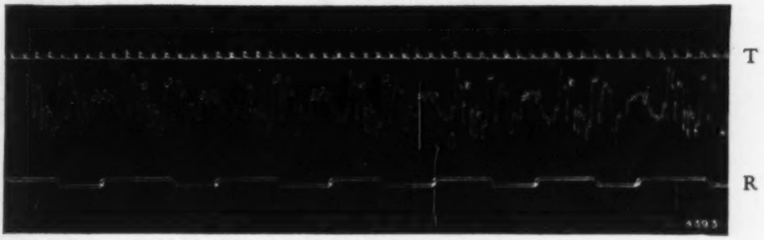


Fig. 620

Two electromagnetic marking mechanisms are fitted, so that a time scale, general tenths of a second, can be marked on the film by one mechanism, while the revolutions of the engine, or other shaft under test, can be recorded by the other mechanism. In each case, this is done by means of a separate stylus operating on the back of the film, so that it is possible for the stylus making the record of accelerations to pass over the whole of its range without fouling either the time-marking or the revolution recording stylus. The instrument can be operated, and the film speed adjusted, electrically from a distance.

Fig. 619 and 620 are photographic enlargements of original records taken on a six-cylinder compressor coupled to a 90-ton flywheel driven by a 400 H.P. turbine through double reduction gearing (ration 100:3). Fig. 619, taken on the shaft at the inner end of the compressor with a turbine speed of 2,410 r.p.m. shows an angular oscillation of the shaft, the semi-amplitude of which varies from 0.024 to 0.030 degrees. In Fig. 620, taken at the outer end of the compressor shaft at the same speed, the semi-amplitude of the angular oscillation is 0.052 degrees, the vertical scale of the record being only half that of Fig. 619, owing to the use of a smaller driving pulley on the compressor shaft. It will be seen that the complicated series of rotational vibrations in Fig. 620 is clearly recorded, and repeated in detail from one revolution to another. T and R show the time and revolution records.

Hasler-Tel Acceleration and Deceleration Recorder. This Swiss-made instrument (R. W. Cramer & Co., U. S. agents) is a rotational accelerometer in construction but it is designed for connection to the speedometer sprocket of automotive vehicles the performance of which is to be investigated. Its outside appearance was shown in Fig. 523, the Hasler-Tel speed recorder, from which it differs in that the chart is *not* time-driven.

The principle of the mechanism is that of time-distance integration. A time-measuring shaft (I in Fig. 621) is in gear with a clockwork mechanism and turns at a constant speed. A distance measuring shaft (II) is in gear with the driving spindle of the instrument and turns at a rate proportional to the speed of the vehicle. The integration of these two measuring elements is accomplished through a system of three cams (T) on the time shaft and of three clutches (KK_1) on the distance shaft, through conjugating levers (H) actuated by the shape of the cams to engage and disengage the clutches through successive seconds. These cams serve to span successively time units of exactly one second each, during which the time shaft and the distance shaft are conjugated, the resulting integrated speed being measured by the deflection of one of three measuring wheels (Z) which carries along in its movement a stirrup (U) under spring tension. The movement of this stirrup is transmitted to the indicating pointer, and by means of gears and a toothed rack to the recording scriber arm.

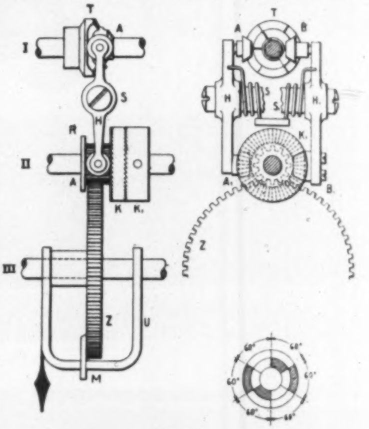


Fig. 621

The stirrup is always carried by whichever measuring wheel has the greatest angular deflection. If the speed is increasing, the stirrup will be moved on farther in the successive seconds; but if it is diminishing, the stirrup will be moved back. Thus the pointer as well as the recording scriber are always set anew every second to the mean speed of the last preceding second.

The movement of the paper chart is in proportion to distance or revolutions.

The graph is drawn uninterruptedly in the form of successive steps up or down, the ordinate from the zero line of the chart to any horizontal speed mark being the speed. The acceleration or deceleration is the difference in height between any two successive speed ordinates.

To determine the total number of feet or revolutions on an acceleration run, it is only necessary to measure the length of paper fed from the first second of the run to the beginning of the line marking the top speed (from A to E in Fig. 622).

To determine the total number of feet or revolutions on a deceleration run measure the length of paper fed from the first second of the run to the end of the graph (from E to J).

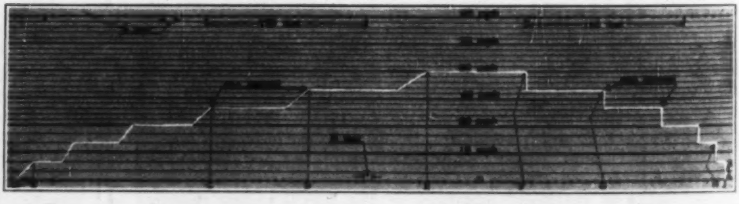


Fig. 622

Measurement of Air Flow

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CHAPTER IX (Cont'd)

Other Types of Manometers.—From the gauges described above it will be possible to select, at a moderate cost, an instrument suitable to most of the conditions that will have to be met in practice. It must not, however, be thought that the types mentioned represent all the instruments worthy of consideration. For further information reference may with advantage be made to a paper by Hodgson * which contains much interesting and useful matter.

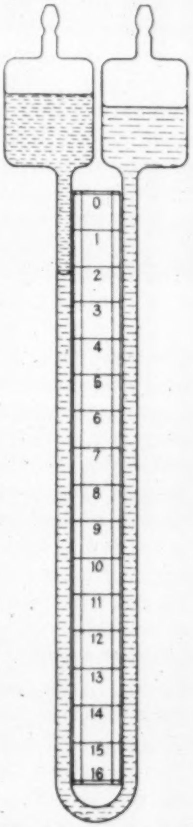

Fig. 60.—Two-liquid differential manometer (parallel tubes).

Before leaving the subject, however, we may consider briefly two further types of sensitive manometers. The first of these, which is due to Hodgson,† is an inclined tube instrument, having a large reservoir fitted with a cylindrical displacer, partly immersed and partly above the liquid in the reservoir, and actuated by means of a vertical micrometer screw. The liquid meniscus in the inclined tube is maintained at a fixed mark, any departure therefrom, due to the applied pressure difference, being compensated by an appropriate vertical motion of the displacer, which alters the liquid level in the reservoir. The meniscus is specially illuminated and is viewed through a microscope having a magnification of 60. The calibration is determined by the relation between the internal diameter of the reservoir and the external diameter of the displacer, so that the instrument may be used as a fundamental standard. The manometer is relatively expensive, but it is robust and portable, and the sensitivity claimed for it is within 0·00002 inch of water. This high precision is attained by the use of a displacer having a small diameter in relation to that of the reservoir.

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* "The Measurement of Pressure," *Proc. Inst. Marine Engineers*, vol. 36, Sept., 1924.

† Described in a paper by D. Hay and W. E. Cooke read before the Institution of Mining Engineers on 19th March, 1926.

The second type of sensitive gauge mentioned above is a modification of the Chattock manometer, recently used for a special investigation at the National Physical Laboratory.* Its special feature is the rotation of the glass-work about a vertical axis until the vertical plane through the axes of the cups makes a small angle—10° or so—with the axis of tilt of the frame. In the normal gauge this angle is 90°. This has the same effect as using a gauge-glass having the cup centres considerably closer together than the usual distances of 13 inches or 26 inches. The sensitivity is increased in proportion, but in order to make full use of this improvement, a high-powered microscope is necessary. It is also advisable to use a gauge-glass fitted with Duncan's temperature compensating vessel.

Calibration of Manometers.—In calibrating any type of manometer against a standard, it is convenient to take simultaneous readings of the two instruments when one side of each is connected to the same source of pressure, which can be varied at will, the other sides being open to atmosphere or to any constant pressure. For the standard, it is necessary to use an instrument such as the tilting micromanometer, from whose indications, which depend solely upon its mechanical construction and dimensions, the applied pressure differences can be accurately calculated.

The simplest method of conducting the calibration is to open one side of each gauge to atmosphere, and to connect the other sides together through a T-piece and tap by means of which the pressure can be applied to both gauges simultaneously. This method is subject to three serious disadvantages. In the first place, when the tap on the variable pressure side is shut the connecting tubes will enclose a small volume of air, and the small local atmospheric temperature fluctuations which are continually occurring will produce serious changes in the readings of both gauges, so that simultaneous observations of both under steady conditions will not be possible. A similar effect arises from the alteration in the enclosed volume while the standard instrument is being adjusted. This volume should be sufficiently large to render negligible the pressure changes to which it is subjected by the movement of either gauge. Finally, when very small pressure differences are being measured the atmosphere cannot be considered as a source of constant pressure. The small local variations of pressure due to draughts and similar causes would make the attainment of steady conditions impossible if this crude method of calibration were adopted.

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* Simmons and Jones, *Reports and Memoranda No.* 1103 *of the Aeronautical Research Committee.*

A logical extension of the above method in the light of these considerations leads to the system of connections for manometer calibrations shown in Fig. 61, by means of which a sufficient degree of steadiness is secured. Corresponding sides of both gauges are connected in parallel, as shown, to two reservoirs which are completely immersed in a water bath to reduce temperature variation effects. One of these reservoirs, A, forms the constant pressure side, and has no other connections; the pressure in the other, B, can be varied through a second tube leading into it. It is advisable, if possible, to arrange the gauges so that a movement in the positive direction is obtained by decreasing the pressure in B below atmospheric.

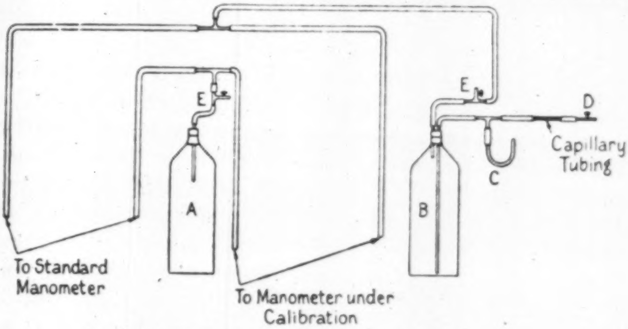

FIG. 61.—System for calibration of manometers.

The pressure can then conveniently be varied by sucking some of the air out of the reservoir; in this way the enclosed air is not warmed as it would be if the pressure were raised by blowing. In order to avoid sudden large variations of pressure while air is being sucked out of B and to provide a means of controlling the applied pressure difference with some degree of precision, it is advisable to have a length of about 4 inches of capillary tubing in the circuit. A further useful addition is the U-tube water manometer C, from which the approximate pressure in B can be observed, so that the tap D can be closed when the desired pressure difference is obtained. It is convenient also to provide bye-passes EE and taps, so that the two reservoirs and both sides of the gauges can be opened to atmosphere to enable zero readings to be taken when required.

For the reasons stated above, the two reservoirs must be of considerable volume: quart Winchester flasks are about the minimum size that should be employed. Some difficulty is usually experienced in making a flask of this type leak-tight. The writer has found that an effective method is to insert the cork or rubber bung with the necessary glass connecting tubes, and then to tie a cylinder of stout paper tightly round the neck, and to pour in sufficient molten paraffin wax to cover the bung and holes through which the glass tubes enter. When solid the wax forms an efficient seal.

By means of this arrangement, calibrations can be rapidly and accurately performed, preferably by two observers taking simultaneous observations on the two gauges.

Testing for Leaks.—In all air-flow measurements involving observations of pressure, care should be taken to ensure the absence of leaks in the various instruments, connections, and lengths of rubber tubing employed. Glass joints, such as taps and the caps of the two vessels of the tilting micrometer, should be greased with a thin coating of vaseline, and all parts of the pressure circuit should be tested for leaks. Particular attention should be paid to the concentric type Pitot and static tube, which is liable to develop internal leaks from one tube to the other, and to all rubber tubing, which is apt to perish and crack, especially at the ends where it is stretched over metal or glass connecting pieces. Even new rubber tubing should not be regarded as above suspicion. The author has found appreciable porosity in rubber tubing taken directly from stock. It is advisable therefore to test separately each length of rubber tube used.

A simple leak tester is shown in Fig. 62. It consists of a small U-tube water gauge with two connecting tubes to one of its limbs. One end of the tube or connection to be tested is connected to the tube A by means of a piece of rubber tubing, which has previously been ascertained to be itself free from leaks: the other end is closed, and a small pressure (about 1½ inches to 2 inches of water) is applied by blowing gently through the tube B and closing the tap before the pressure is released. Any small leaks will now be indicated by a gradual creep of the water levels in the two limbs. In order better to observe the motion, it is convenient to have a number of horizontal lines about ½ inch apart ruled on the board to which the U-tube is fixed. The function of the two bulbs in the leak tester is to reduce the risk of ejecting water from the limbs if excessive pressure is inadvertently applied.

In testing concentric Pitot and static tubes for leaks, each tube should be dealt with separately: no difficulty will be found

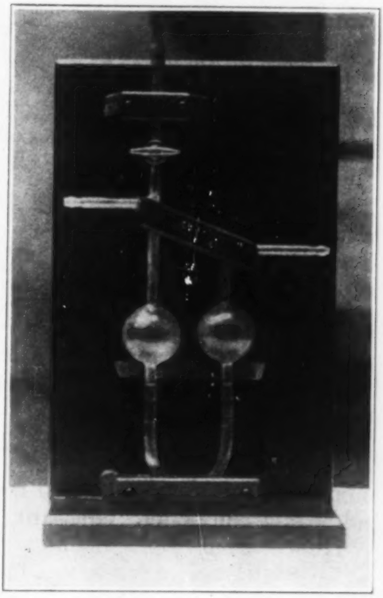

FIG. 62.—Leak tester

in the case of the impact tube, since its end can be effectively closed by pressing the ball of the thumb against it. In order to test the static tube, the static holes are best closed by winding tightly round the portion of the tube in which the holes are situated, three or four thicknesses of rubber tape as used for electrical insulation.

As regards choice of rubber tubing, it will be found that for general use fairly thick-walled tube of red rubber, having a bore of $\frac{3}{16}$ inch and an external diameter of about $\frac{3}{8}$ inch will be the most suitable. Such tubing will usually be found to be non-porous and considerably more permanent than thin black tubing, which is not to be recommended for this type of work. It is probably also to be preferred to the thick-walled pressure tubing on account of the greater ease of making connections.

Theory of the Curved Tube Manometer.—We shall assume that the manometer is intended to be used with a standard Pitot and static tube. If, then, p is the pressure difference in pounds per square foot that this instrument transmits to the manometer when used in a wind of v feet per second, we have the equation

$$p = \tfrac{1}{2}\rho v^2.$$

If h is the corresponding height in inches through which the level of the manometric liquid rises above its zero level (we shall take the reservoir to be sufficiently large to warrant the assumption that all the change in level occurs in the curved tube),

$$5{\cdot}2\,\frac{h}{\sigma} = \tfrac{1}{2}\rho v^2,$$

where σ is the specific gravity of the manometric liquid.

Hence
$$v\sqrt{\rho} = \sqrt{\frac{10\cdot4h}{\sigma}}. \qquad (8)$$

In Fig. 63 let O be the zero position of the liquid meniscus against the upper side of the curved tube, and take O as the origin of co-ordinates. The condition to be fulfilled is that for a given increment in $v\sqrt{\rho}$ the meniscus is to move a given distance along the tube to O′. Hence the equation of the curve of the tube is

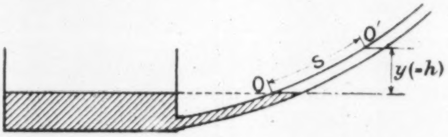

FIG. 63.

$$s = Av\sqrt{\rho}, \qquad (9)$$

where s is the distance moved measured along the tube from O and A is a convenient constant.

Hence, from (8),

$$s = A\sqrt{\frac{10\cdot4}{\sigma}\,h} = B\sqrt{h}.$$

If x and y are the co-ordinates of O′, measured from the origin O,

$$s = B\sqrt{h} = B\sqrt{y}.$$

Differentiating, we have $ds = \frac{B}{2\sqrt{y}}\,dy$,

i.e.
$$\sqrt{dx^2 + dy^2} = \frac{B}{2\sqrt{y}}\,dy,$$

or
$$\frac{dx^2}{dy^2} = \frac{B^2}{4y} - 1.$$

Hence
$$dx = \sqrt{\frac{B^2}{4y} - 1}\,.\,dy,$$

and the curve to which the tube is to be bent is obtained by integrating this equation. This gives

$$x = \int\sqrt{\frac{B^2}{4y} - 1}\;dy + C.$$

The right-hand side is easily evaluated by the substitution $y = \frac{B^2}{4} \sin^2 \theta$, and the final expression will be found to be

$$x = \frac{B^2}{4} \sin^{-1}\sqrt{\frac{4y}{B^2}} + \frac{B}{2}\sqrt{y\left(1 - \frac{4y}{B^2}\right)}. \quad . \quad (10)$$

The constant of integration C is found to be zero by putting x and y equal to 0 simultaneously at the origin.

If, therefore, the axis of the tube is bent to the form represented by equation (10), the gauge will show equal movements of the liquid meniscus along the tube for equal changes in $v\sqrt{\rho}$. Instruments constructed on these lines require calibration against a standard manometer, just as in the case of the ordinary inclined tube gauge.

It is clear from the above analysis that if the instrument is furnished with a velocity scale, this can only be accurate at one value of the air density ρ, which must be specified. For any other density ρ', the readings must be multiplied by $\sqrt{\frac{\rho}{\rho'}}$; that is, if the scale is said to be accurate for air (assumed dry) at a temperature T absolute and at a pressure p, then the readings for a temperature T′ and a pressure p' must be multiplied by $\sqrt{\frac{T'p}{Tp'}}$.

Control and Instrument Board in the Main Operating Room of the Conowingo Station of the Philadelphia Electric Company

Measurement of Air Flow

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CHAPTER X.

METHODS OF FLOW MEASUREMENT BASED UPON THE RATES OF COOLING OF HOT BODIES.

THE relation between the rate of loss of heat of a heated body and the speed of flow of a fluid in which it is immersed has formed the subject of a considerable amount of research. Attention has mainly been concentrated on problems connected with the use of electrically heated wires as anemometers, but recently a new line of investigation has been developed in which a specially constructed alcohol thermometer is employed in a similar manner. The laws governing the convective cooling of hot cylindrical wires by streams of fluids are now, empirically at all events, fairly well understood, and measurements of air flow have successfully been made in large numbers of cases by methods based on these laws. Whilst such methods possess definite advantages, chief among which is the possibility of obtaining high sensitivity for low rates of flow, certain manipulative difficulties have hitherto prevented them from coming within the domain of general practical anemometry. Nevertheless, for special work, particularly under laboratory conditions, instruments utilising these principles may be made to yield excellent results, and for this reason it has been thought desirable to include a comparatively brief discussion of the subject here. Further information may be obtained by reference to the original papers quoted in the bibliography at the end of this chapter, and to other sources cited in these papers themselves.

The Cooling of Heated Wires.—The most extensive researches into the laws of cooling of electrically heated wires are probably those of L. V. King.* Developing the theoretical treatment initiated by Boussinesq,* King showed that the relation between the heat lost H per unit length of a cylinder of diameter *d*, maintained at a temperature T above that of the fluid in which it is immersed, could be represented very nearly by the equation

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* Boussinesq. *Comptes Rendus*, vol. 133, p. 257, and *Journal de Mathématiques*, vol. 1, p. 285. Theoretical discussion of heat losses from bodies of various shapes immersed in a stream of fluid.

L. V. King. *Phil. Trans. Roy. Soc.*, vol. 214, 1914, p. 373.

$$H = KT + \sqrt{2\pi KS\sigma d}\ V^{\frac{1}{2}}T, \quad . \quad . \quad (1)$$

where K is the thermal conductivity of the fluid, S its specific heat at constant volume, σ its density, and V its velocity.

King showed that this expression might be expected to hold down to a value of V*d* of 0·0187, V being expressed in centimetres per second and *d* in centimetres, which is equivalent to a limiting speed of about ¼ foot per second for a wire of diameter 0·001 inch. It should be noted—and attention is drawn to this point by King—that in deriving the theoretical relationship (1) it is assumed that V is the total speed of the fluid past the wire. Now a heated wire placed in air will give rise to convection currents which will assist in the cooling of the wire, and at very low velocities these currents may have an appreciable effect in modifying the true speed of the air past the wire. It is probable therefore that in practice the lower limit of the speed range over which (1) is applicable will be somewhat higher than its value as given by the abovementioned criterion.

Equation (1) may be written in the form

$$H = B\sqrt{V} + C, \quad . \quad . \quad . \quad (2)$$

where B and C are functions of temperature and the properties of the fluid and the wire mentioned above. For a wire of given dimensions, maintained at a constant excess temperature, and always used in the same fluid (air, for example) B and C are constants, and may be calculated for the prescribed conditions. In order to verify his theoretical deductions, King undertook a comprehensive experimental investigation of the heat losses of electrically heated platinum wires ranging in diameter from about 0·001 inch to 0·006 inch when moved, on a rotating arm, through still air at speeds between about 0·5 and 29 feet per second. He found that, within these limits, the results could be accurately expressed by an equation of the form of (2), and further work carried out by him and other investigators has shown that this equation holds also for speeds up to at least 100 feet per second. The actual values of B and C determined by King were in moderately good agreement with those calculated from theory.

The Use of Electrically Heated Wires in Anemometry.—If a current *i* ampères is flowing in a wire of resistance R ohms the heat generated per second is equal to $\frac{i^2R}{J}$ calories, where J is the mechanical equivalent of heat in joules per calorie. Hence for an electrically heated wire equation (2) becomes

$$\frac{i^2R}{J} = B\sqrt{V} + C. \qquad (3)$$

Now if the temperature of the wire is maintained constant, its resistance R will also be constant, and if we confine our attention to a particular fluid, (3) becomes

$$i^2 = K_1\sqrt{V} + K_2, \qquad (4)$$

where K_1 and K_2 are constants for a given wire.

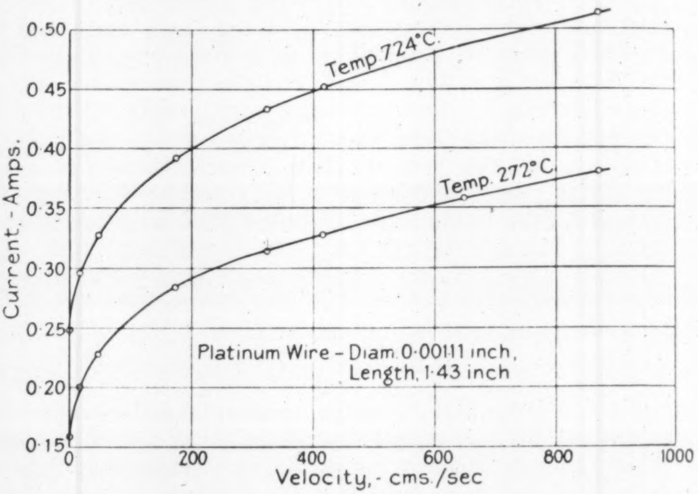

FIG. 64.

This relation between current and air speed for a wire maintained at a constant temperature in air is shown graphically in Fig. 64, which is taken from King's results. The upper curve was obtained with the wire at a temperature of 724° C., whilst for the lower curve the temperature was 272° C. These curves show well the special characteristic of the hot-wire anemometer, namely, the high degree of sensitivity at low wind speeds. It will be seen that the rate of change of current with wind speed is much more rapid at the lower speeds than at the higher, and also that the higher the temperature of the wire, the higher is the sensitivity over the whole range.

Turning once more to equation (4), we see that if i_0 is the value of the current necessary to maintain the wire at a prescribed constant temperature in still air (i.e. when $V = 0$), $K_2 = i_0^2$ and we may write

$$i^2 = i_0^2 + K\sqrt{V} \qquad (5)$$

as the relation between current and wind speed in its most useful practical form. The heat loss represented by $i_0{}^2R$ is the total loss due to radiation and convection in still air. For the reasons stated above, when V is so low that it becomes comparable with the speed of the free convection currents due to the hot wire in still air, equation (5) requires modification, but for ordinary purposes this will not be necessary. Some calculations made by King indicate that for a wire 0·003 inch diameter the free convection current has a velocity of the order of ½ foot per second when the wire is at 1000° C., and about ¼ foot per second at 200° C. If, therefore, a wire is to be used to measure low speeds of magnitudes comparable with these, the calibration should be determined from tests at such speeds.

Effect of Variation of Atmospheric Conditions.—The variable most affecting the relation between the current in a given wire and the wind speed is atmospheric temperature. From what has been stated above, it will be clear that equation (5) only holds when the wire is maintained at a constant temperature, and that the values of i_0 and K, once determined, only relate to a definite *excess* temperature of the wire over the surrounding air. Any change in the air temperature will therefore produce a change in the calibration curve of a given wire. Changes in air density due to variations of atmospheric temperature also need consideration. If we assume that the other quantities occurring in equation (1), viz. the specific heat and conductivity of the air, are not affected by variations in atmospheric temperature, and if we retain T as a variable, equation (1) may be reduced to the form

$$i^2R = C_1(T_w - T_a) + C_2(T_w - T_a)\sqrt{V\sigma}, \quad . \quad (6)$$

where $T = T_w - T_a$ = wire temperature − atmospheric temperature,

$$C_1 = \text{constant} = \frac{i_0{}^2R}{T_w - T_a},$$

$$\text{and } C_2 = \text{constant}.$$

Equation (6) may be written

$$\sqrt{V\sigma} = \frac{i^2R - C_1(T_w - T_a)}{C_2(T_w - T_a)} \quad . \quad . \quad . \quad (7)$$

Treating T_w as constant (hence R is also constant) and $(V\sigma)$ as a single variable, and differentiating with respect to T_a, we have

$$\frac{1}{2\sqrt{V\sigma}}\,\frac{d(V\sigma)}{dT_a} = \frac{i^2R}{C_2(T_w - T_a)^2}. \quad . \quad . \quad (8)$$

Equations (7) and (8) may be combined to give, when $\frac{i_0{}^2 R}{T_w - T_a}$ is written for C_1,

$$\frac{d(V\sigma)}{(V\sigma)} = \frac{2dT_a}{T_w - T_a} \frac{i^2}{(i^2 - i_0{}^2)}, \quad . \quad . \quad . \quad (9)$$

which shows the fractional change in $V\sigma$ for a change in air temperature given by dT_a.

For a platinum wire 0·0025 inch in diameter employed at 1000° C. King gives $i_0{}^2 = 0{\cdot}5$ (amps.)^2 approximately, whilst for a range of velocities from 16·4 to 92 feet per second i varied between 1 and 2 ampères. If these values are substituted in (9) it will be seen that a change of air temperature of $\pm$ 2°C. produces a change in $(V\sigma)$ of less than 1 per cent. over this range of air speed. If the air temperature changes by more than this amount a correction can easily be applied by the use of (9).

The other effect of a variation in T_a, to which reference has already been made, is the accompanying change in the density σ. In this it is associated also with changes of barometric pressure and humidity. The equations already given show that the hot wire really measures the product of velocity and density. If therefore a given wire is calibrated in terms of velocity, this calibration will only hold for a given value of σ. It will readily be seen from equation (6) that if V is the velocity corresponding, according to the calibration curve for density σ_0, to a current i, the same current will correspond, when the density is σ_1, to an air speed $V\frac{\sigma_0}{\sigma_1}$. The densities σ_0 and σ_1 are easily calculable from observations of air temperature and barometric pressure. Relative humidity may also be taken into account if desired, but its effect will rarely be important.

In the above analysis it has been assumed that changes of atmospheric conditions do not affect the other properties of the air appearing in equation (1), viz. the specific heat and the thermal conductivity. This assumption will be true for all practical purposes even under extreme variations in natural conditions, but for special work, such as, for example, the measurement of the flow of hot air, the possibility of variations in these properties should not be overlooked.

Measurement of Air Flow

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CHAPTER X (Cont'd)

Methods of Measurement in Hot-Wire Anemometry.—It has been shown above that if a wire is maintained at a constant temperature (and consequently also at a constant resistance) the current varies with the wind speed according to the law expressed by equation (5). Alternatively, if the current passing through a wire is kept constant its temperature and resistance will vary with the wind speed in a definite manner. There are, accordingly, two possible methods of measurement, which we may term respectively the constant resistance method, and the constant current method. Experiments by Simmons and Bailey * show that, except at low wire temperatures (less than about 150° C.), the constant current method leads to higher sensitivity. In practice the constant resistance method is, however, probably to be preferred, partly on account of the fact that it is somewhat easier accurately to maintain a constant resistance than a constant current, and partly because the constant K in equation (5) can then be determined by a calibration at a single air speed, i_0 being the current necessary to bring the wire to the desired resistance in still air. On the other hand, the constant current method allows, as we shall see, a direct reading of wind speed to be obtained.

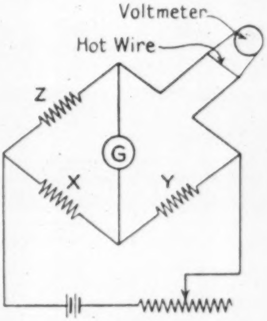

Fig. 65.

(*a*) *Constant Resistance Methods.*—In the simplest case, the hot wire forms one arm of a Wheatstone bridge—see Fig. 65, the opposite arm Z consisting of a manganin resistance having practically zero temperature coefficient. The hot wire is of some pure metal, such as nickel or platinum, whose electrical constants are accurately known; the resistances forming the

Editor's Note: Ower's "Measurement of Air Flow" can be obtained in book form from the Instruments Book Shelf at $5.00 post paid.

other three arms of the bridge can accordingly be arranged so that, when the bridge is in balance, the resistance, and consequently the temperature, of the hot wire is at its desired value. Any change in the speed of the air current past the hot wire will then necessitate a change in the heating current in order to restore the temperature of the wire to its former value. When the wire is again at this temperature the bridge will once more be in balance, and the change in current will be a measure of the wind speed.

The current may be measured in a number of ways. An ammeter of the requisite sensitivity and range may be connected in series with the hot wire, so that the current passing through it can be measured directly, or a high resistance voltmeter connected across the wire may be used as a measure of the current, and hence of the wind speed, since the wire always has the same resistance. Alternatively, the current in the external circuit may be measured by an ammeter. For the highest accuracy the scheme illustrated in Fig. 66, which was used by Simmons and Bailey,* is recommended. Here the current in the external circuit is measured by a potentiometer method; the voltage drop across a standard known resistance R, having a negligibly small temperature coefficient, is determined, and the current flowing can easily be calculated. The standard cell shown in the diagram is used to calibrate the potentiometer directly in terms of voltage. Since no current flows when balance of the galvanometer G_2 is obtained during standardisation of the potentiometer, the voltage across the portion AB is equal to the known voltage of the standard cell. A small variable rheostat, as shown, is connected in series with the potentiometer cell in order that balance of the standard cell may always be obtained at the same potentiometer reading, in spite of fluctuations in the voltage of the potentiometer cell.

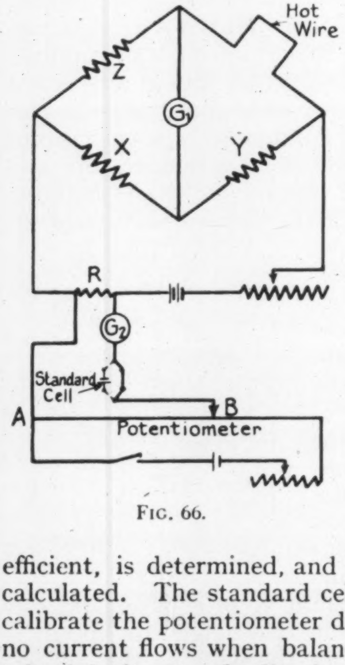

FIG. 66.

The usual arrangement of the arms of the bridge is to make the two ratio coils X and Y of equal resistance, and the manganin resistance Z equal to that of the hot wire when the latter is at its desired temperature. This value can of course be calculated beforehand from a knowledge of the temperature-resistance coefficient of the material of which the wire is composed. The ratio coils should be of the same material, preferably manganin.

As regards the temperature of the hot wire, it follows from equation (9) that the higher the temperature excess $T_w - T_a$, the smaller will be the errors due to changes of atmospheric temperature. If, therefore, it is desired to avoid the necessity for applying temperature corrections, it will be necessary to run the wire at a high temperature. King advocated a working temperature of 1000° C., for which, as we have seen, the errors in the measurements of V will not often exceed 1 per cent., if the initial calibration is performed at, say, 17° C. In order to maintain a high working temperature such as this, fairly large currents are required at the higher wind speeds, and in these circumstances it may be desirable to use, as King did, a Kelvin double bridge in place of the ordinary Wheatstone net. A description of this form of bridge, which allows large currents to be passed through the anemometer wire without overloading the ratio coils, will be found in any text-book dealing with electrical measurements. It has the additional advantage of high sensitivity, and that its readings are, to the order of accuracy required for hot-wire anemometry, independent of contact and lead resistances. The latter feature is of importance for some types of work, as it allows the hot wire to be mounted on a moving body, the current being led to it through brush contacts or slip rings.

Although the use of a high working temperature has the merits of increased sensitivity and the reduction of errors due to small changes of air temperature, a temperature as high as 1000° C. is not to be recommended for general purposes. In the first place, there is a risk of fusing the anemometer wire by the accidental passage through it of a comparatively small excess of current, especially when working at low wind speeds. Secondly, there is an "ageing" effect, mentioned by King and found by Simmons and Bailey* to be quite appreciable with fine wires (0·001 inch diameter). This effect causes progressive changes in the calibration of a given wire, and there is evidence to show that it is more important the higher the working temperature. It seems, therefore, preferable to work with the anemometer wire at some lower temperature, say 400° C. to 500° C., and either to correct if necessary for atmospheric temperature variations by the use of equation (9), or to adopt some form of circuit which automatically compensates for such variations.

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* Simmons and Bailey. *Phil. Mag.*, vol. 3, 1927, p 81.

King described a method * by which the readings obtained from the Kelvin double bridge can be made to indicate velocity independently of the air temperature, to the degree of accuracy required in practice. Certain of the ratio coils, instead of being made of manganin, are made of the same material, in this case platinum, as the hot wire, so that they have the same temperature coefficient of resistance. These coils are exposed to the airstream so that they can readily attain its temperature.

A method of temperature compensation suggested by Davis * is illustrated in Fig. 67. The three resistances X, Y, and Z are of manganin, whilst in the arm of the bridge containing the resistance Z there is a second coil P which can be short-circuited by means of the key K. The connections are so arranged that when this coil is short-circuited the current through the bridge is automatically decreased about one hundredfold, so that only a very small current passes through the anemometer wire. The latter now acts as a platinum resistance thermometer, and by moving the contact C along the slide wire SS the bridge is balanced at a definite position depending on the temperature of the air flowing past the anemometer wire. If required, a scale of air temperature may be marked along SS. The contact is fixed at the balance-point on SS, and the key is now raised. This process increases the resistance of that arm of the bridge by the resistance P, which is constructed of manganin and is therefore unaffected by ordinary temperature changes, and simultaneously sends a much larger current through the whole bridge, so that the hot wire is heated. This current is then adjusted by the rheostat until balance is again obtained. It will be clear that the resistance of the anemometer wire is then increased by an amount equal to the resistance of P. If the resistance-temperature law for the anemometer wire is linear it follows that the wire is always heated to a constant temperature excess above the air temperature, and, actually, the departure from this condition is not sufficient to cause appreciable errors. For his anemometer wire Davis used platinum, 0·006 inch diameter, heated to 108° C. above atmospheric temperature.

A valuable method of measurement, due to Professor Callendar, has been described by R. O. King.* In series with the external circuit of the Wheatstone bridge, is a device called a volt-thermometer (Fig. 68), which consists simply of a length of fine platinum wire whose function is described below. In the bridge itself, the two ratio coils X and Y are of manganin, having resistances of 100 ohms and 400 ohms respectively, whilst the standard resistance Z is 1 ohm

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* L. V. King. *Phil. Trans. Roy. Soc.*, vol. 214, 1914, p. 373; also *Phil. Mag.*, vol. 29, 1915, p. 556; also *Journ. Franklin Inst.*, vol. 181, 1916, p. 1, and vol. 183, 1917, p. 783.

Davis. *Proc. Phys. Soc., Lond.*, vol. 33, 1921, p. 152.

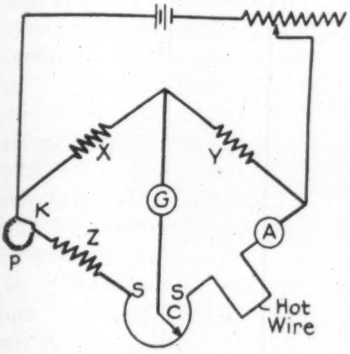

FIG. 67.

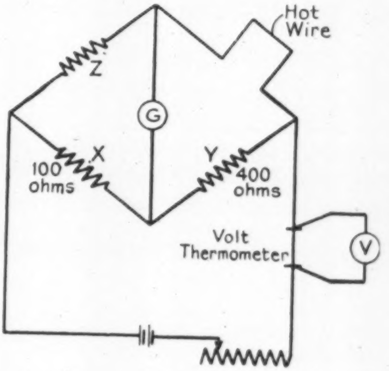

FIG. 68.

and the anemometer wire 4 ohms when hot. It will be clear therefore that no appreciable error is made in assuming that the current through the volt-thermometer is equal to that through the anemometer wire. Instead of observations of this current, measurements of the voltage drop across the volt-thermometer are made. As the external current is altered to maintain balance of the bridge, so the heating effect of this current through the volt-thermometer wire changes its temperature, and consequently its resistance and the voltage drop across it. Callendar has shown experimentally that over a considerable range there is a linear relation between the resistance R of the wire and the voltage drop V, and that for a 3-inch length of 0·004 inch diameter platinum wire this relation can be written

$$R = 0{\cdot}607V + 1 \text{ ohm}. \qquad (10)$$

Hence, if C is the current through the anemometer wire, since this current may be taken as flowing also through the volt-thermometer, we have

$$C = \frac{V}{R} = \frac{V}{0{\cdot}607V + 1}. \qquad (11)$$

Plotting this relation between C and V (Fig. 69), we see that

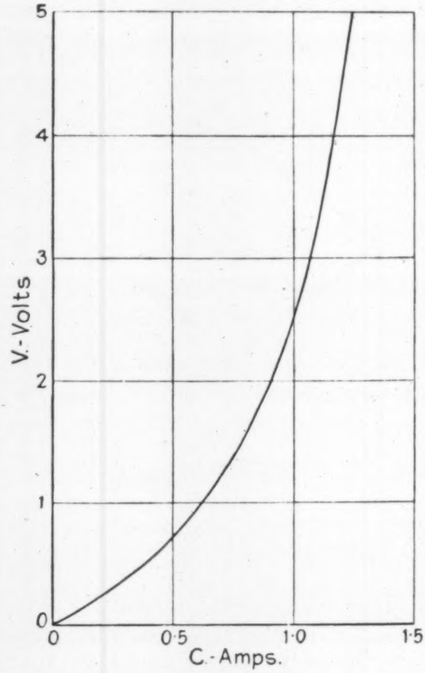

FIG. 69.

V increases rapidly with C, the rate of increase being, in fact, somewhat faster than the square of the current. The physical significance of this is that as the current in the wire is increased its temperature rises rapidly. Its resistance therefore increases at a proportionate rate, so that a rapidly rising voltage drop occurs across the wire. This point is well illustrated by the curve of Fig. 70, given by Simmons and Bailey,* which shows the rapid rise of temperature with heating current in still air of a platinum wire 0·00105 inch in diameter and 3·07 inches in length.

It will be seen therefore that, whereas in the ordinary method of measurement the air speed varies, according to equation (5), approximately as the fourth power of the quantity observed, viz. the current in the anemometer wire, it can be made to vary as some power between 1 and 2 of the observed reading if the latter is the voltage drop across the volt-thermometer wire, instead of the heating current. A valuable increase in accuracy is thus afforded by this method. A further important feature is the possibility of extending considerably the range of air speed that can be observed with one measuring instrument—in this case, a voltmeter. For if two similar volt-thermometer wires are used in parallel in place of the single wire, only half the total current will flow through each, and consequently a full scale deflection of the voltmeter connected across these wires will correspond to twice the total current passing when one wire is used. That is, since the wind speed is approximately proportional to the fourth power of the current, a given voltmeter deflection will correspond to roughly 2^4 or 16 times the wind speed which it previously indicated. It is claimed that the accuracy attainable is well within 1 per cent. for all speeds up to about 300 feet per second. The factor limiting the indefinite extension of the scale in this way will be the maximum current that can safely be passed through the circuit.

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* Simmons and Bailey. *Phil. Mag.*, vol. 3, 1927, p. 81.

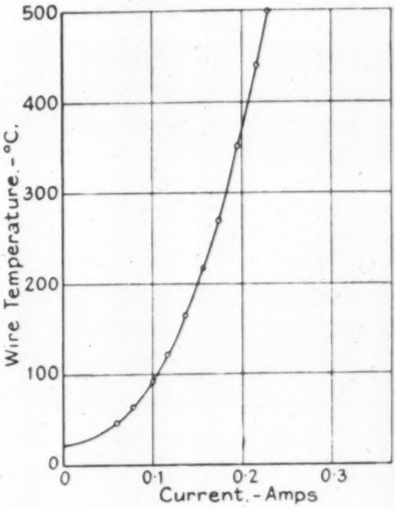

FIG. 70.

R. O. King * has described an actual anemometer working on these lines. The anemometer wire was of 0·004 inch diameter platinum having a total length of 6 inches, arranged in four sections. The volt-thermometer consisted of four platinum wires, each 0·004 inch in diameter and 3 inches long, with the necessary connections so that one wire alone, or two, three, or four in parallel, could be used as required to give the maximum accuracy for any particular air speed being measured. It was found that a single platinum wire of these dimensions would safely take a current producing a 5-volt drop across it. In order to prevent the loss of heat by convection from the volt-thermometer and to protect it from draughts, its four wires were enclosed in a fairly air-tight box. This arrangement was found to be satisfactory up to values of the total current of about 2 or 2½ ampères. For measurements of high rates of flow, where the current attained the order of 5 ampères, it was found necessary to water-jacket the box containing the volt-thermometer wires in order to maintain sufficiently constant temperature conditions at the wires. A five-range voltmeter, reading up to 5 volts, was used with this anemometer.

(*b*) *Constant Current Method.*—A hot-wire instrument based

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* R. O. King. *Engineering*, vol. 117, 1924, pp. 136 and 249.

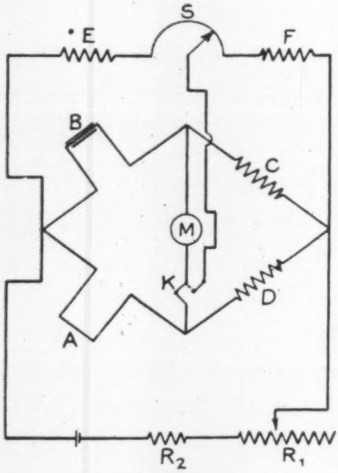

FIG. 71

upon this method of measurement has been designed by MacGregor Morris, and has been put on the market for the measurement of low air speeds. Fig. 71 shows the essential features of the circuit used. The anemometer wire A is of nickel, 0·005 inch in diameter and about 6 inches long, having a cold resistance of about 0·9 ohm. B is a similar nickel wire, and C and D, which form the other arms of the bridge proper, are manganin resistances of 1 ohm each. The galvanometer used in the constant resistance circuits as a null reading instrument to indicate balance of the bridge is now replaced by the reading milli-ammeter M. If we assume for the moment that the wires A and B are exactly similar, as are also the resistances C and D, we see that the current in the external circuit will always divide into two currents equal in magnitude through the arms BC and AD. The bridge will be in balance in still air when the resistances of A and B are made equal to those of D and C, that is, when the current in each branch heats the nickel wires sufficiently to raise their resistances from 0·9 to 1·0 ohm. No current will then flow through the milli-ammeter. If now the wire A is exposed to the wind, its resistance will drop and the bridge will no longer be balanced. The milli-ammeter then registers an "out-of-balance" current, which is utilised as a measure of the wind speed.

A special feature of this instrument is the method of compensation against variations of atmospheric temperature. All four wires forming the arms of the bridge ABCD are carried in a frame which is exposed to the air current to be measured. The anemometer wire A is, of course, bare, but the other nickel wire B is shielded by a thin metal tube from the convective cooling of the stream. By means of a simple change-over switch the shielded wire B and the manganin resistance C can be made part of an auxiliary bridge circuit whose other two arms are the manganin resistances E and F of about 20 ohms each. The junction on the bridge between E and F can be varied over the range of the slide wire S, which has a total resistance of about 5 ohms, so that the ratio of the total resistances of the arms E and F can be accordingly varied. The process of switching over to the auxiliary bridge connections automatically connects the milli-ammeter between the junctions of E and F and of B and C. At the same time a large additional resistance is put into the external circuit so that the current through the wire B is reduced to a sufficiently small value to ensure that it produces no appreciable rise of temperature of this wire over that of its surroundings. In this condition B acts as a resistance thermometer, and the auxiliary bridge is balanced at zero on the milli-ammeter scale by moving the adjustable contact over the slide wire S. The balance-point will depend on the temperature of the wire B, that is, in effect, since the tube enclosing this wire is exposed to the air current, on the prevailing air temperature.

A scale of temperature is marked along the slide wire, and the temperature reading at which balance is obtained is noted. The bridge is then thrown out of balance by moving the contact on the slide wire through a definite temperature range, which varies slightly with each instrument, of about 40° F. This alters the ratio of E to F so that balance of the auxiliary bridge can only be restored by sending an increased current through the nickel wire B, sufficient to raise its resistance by an amount equivalent to a definite temperature excess (about 40° F.) over that of the air. With the contact on S in its new position, therefore, the high series resistance in the external circuit is cut out and the current is adjusted by the rheostat R, until balance is again obtained. The instrument is now adjusted ready for use, and the change-over switch is put into the position which brings the main bridge ABCD into the circuit. If the wires are accurately adjusted so that the pairs A and B, C and D are exactly similar, the bridge will be in balance when the air speed past A is zero,* but when the air is moving A will be cooled, whereas B, being shielded, will not; further, C and D, being of manganin, will not alter in resistance. An out-of-balance current will therefore flow through the milli-ammeter, which can be calibrated in terms of wind speed.

If the wires A and B are not exactly similar there will be a slight zero error on the instrument, i.e. a small milli-ammeter deflection at zero wind speed. This, however, can easily be eliminated by arranging the temperature excess to which B is initially set, to be such that when the main bridge is in the circuit the resistances of A and B will be equal, so that the current through A will be equal to that through B. Thus, by a simple alteration of the balance-point on S, which will constitute a constant for the instrument, the main bridge can always be made to balance in still air The wires A and B will then be at slightly different temperatures, but the difference between their temperatures in still air will be constant. It is for this reason, namely, that the wires A and B are not always exactly similar, that the temperature excess to which the auxiliary bridge is to be balanced varies somewhat from one instrument to another. Although there is less difficulty in making the manganin resistances C and D equal, any slight dissimilarity in these can be allowed for by the same means.

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* Apart from very small errors due to natural convection currents from A.

An instrument having resistances and dimensions of wires of the magnitudes mentioned above is suitable for measuring velocities up to 200 feet per minute. A photograph of such an anemometer is reproduced, by the courtesy of Messrs. H. Tinsley & Co., Ltd., the manufacturers, in Fig. 72. The frame carrying the bare and shielded nickel wires and the two manganin resistances forming the other arms of the bridge will be seen to the left of the diagram, the milli-ammeter and the controlling switch and resistances being conveniently arranged in the box on the right. The anemometer wire is always held in a vertical position when in use, so that natural convection currents always act in the same direction relatively to the wire. Calibration of the instrument is also performed with the wire vertical. A two-volt accumulator, fitting into a special compartment in the box, is supplied with the instrument. A small fixed resistance (R_2 in Fig. 71), permanently in series with the battery circuit, is provided, to prevent accidental short-circuiting of the cell.

New Aerial Bomb Sight

IN a new sight, which promises to revolutionize bombing for the Air Corps of the different nations, Mr. Georges Estoppey, working with the Gaertner Scientific Corporation, has developed an instrument with unprecedented improvements over all others previously designed and manufactured. Mr. Estoppey, formerly a citizen of Switzerland, first developed his interest in bomb sights in 1914 among a group of young engineering students with whom he was there associated. Since then he came to this country and started working in the Armament Section of McCook Field, Dayton, Ohio, where he spent seven years. Since that time he has been continuously associated with bombs or allied subjects.

The unique fact, which is indicative of the scientific and mathematical precision used in its design, is that it was first found necessary by Mr. Estoppey to develop or transform the old time honored ballistic formulas into a single new one so that it would render possible corrections for all possible determinate errors. The ballistic corrections are occasioned by over *twenty* different factors or distinct sources. All these corrections, however, are automatically taken care of by merely the adjustment of indexes on three dials.

The main new feature of this bomb sight when compared to others, is its automatic synchronizing device. Experiments in the place of manufacture, on a unique moving carpet to simulate bombing conditions, indicate that the bomb sight can be synchronized with the target within 3 to 5 seconds by an entirely inexperienced operator. The synchronization is entirely automatic, a fact which has not been accomplished by any of the preceding bomb sights. The stabilization of the sight in the aeroplane is accomplished by a damped pendulum arrangement. This makes unnecessary the cumbersome and heavy gyroscopic stablization found in some other sights. The new sight, which is relatively light and very compact, was manufactured by the Gaertner Scientific Corporation. The accuracy, extreme rigidity and simplicity make this bomb sight, known as the D-7, the outstanding bomb sight in aircraft tactics.

Measurement of Air Flow

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CHAPTER X (Cont'd)

Notes on Anemometer Wires.—Platinum has been more extensively used for anemometer wires than any other metal, chiefly because of its chemical inertness to atmospheric conditions even at high temperatures. For low temperature wires, such as those used by MacGregor Morris, nickel has been found to be suitable, provided it is used in a high state of purity. Electrolytically prepared nickel gives satisfactory results.

The dimensions of the wire are of some importance. It would seem that fine wires are more prone to the ageing effect, to which reference has been made previously, than stouter wires. From this point of view, therefore, it is desirable to have wires of large diameter. There is, however, the objection to thick wires that large currents are needed to raise them to the desired temperature ; few, if any, experimenters have used wires exceeding 0·006 inch in diameter.

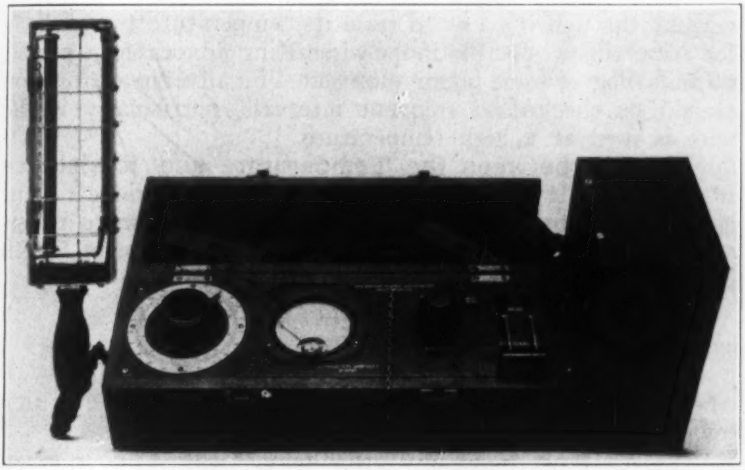

Fig. 72.—The MacGregor Morris hot-wire anemometer.

With regard to length, too short a wire will not give the requisite sensitivity, but a long wire may become somewhat slack when heated and its natural period of vibration may become comparable with the frequency of the eddies generated by the motion of the air past it. There will then be a tendency for the wire to take up an oscillatory motion, which will increase the rate of cooling and cause a spurious velocity reading. If the amplitude of vibration is at all large, the errors due to this cause may be appreciable. In order to avoid risk of such effects it is best to limit the length of the wire and to mount it in such a manner that it is always under tension, which may be conveniently provided by arranging for a certain amount of spring in the wire supports, tending to keep the wire taut. The length of wire is also determined to some extent by the use to which the instrument is to be put. The method of support should be designed to introduce as little disturbance of the airstream as possible, especially if the instrument is to be used in relatively small pipes. Ordinary solder should never be used for attaching the wire to its supports. Hard silver solder is suitable except for very high wire temperatures, when it is better to fuse or weld the wire to its end connections. Before use, a new wire should always be annealed by passing a current through it so as to raise its temperature to red heat for some time. For platinum wires King advocated a period of annealing of some hours' duration. Finally, the calibration should be checked at frequent intervals, particularly if the wire is used at a high temperature.

Relation between the Temperature and Resistance of a Wire.—It is necessary, when designing a bridge to suit a given wire, to make calculations of the approximate resistance of the wire. The resistance of a circular wire of length l inches and diameter d inches at 0° C. is equal to

$$\frac{4lk}{\pi d^2} \text{ ohms,}$$

where k, the specific resistance, may be taken as $4{\cdot}2 \times 10^{-6}$ for platinum and $4{\cdot}6 \times 10^{-6}$ for nickel.

The resistance R_t at any other temperature T° C. is given with sufficient accuracy by the equation

$$R_t = R_0(1 + \alpha T), \quad . \quad . \quad . \quad (12)$$

where R_0 = resistance at 0° C., and $\alpha = 38 \times 10^{-4}$ for platinum and 62×10^{-4} for nickel.

In calculating the temperature of a wire from its measured resistance by the use of this equation, small errors are introduced by the assumption that α is strictly constant, and by neglect of the heat loss by conduction to the wire supports. For approximate calculations, however, this relationship will give sufficient accuracy.

Electric Flow Meters.—Thomas * and Callendar * have designed electrical meters which indicate the rate of flow of air from measurements of the heat energy which must be supplied to the moving stream, at a specified position, in order to maintain a definite difference of temperature between two given sections on either side of that at which the heat is supplied. If $t°$ C. is the constant temperature difference between these sections, the weight of air W flowing per second is given by

$$W = \frac{H}{st} \text{ grams per second,} \qquad . \quad . \quad (13)$$

where H is the heat supplied in calories per second and s is the specific heat of air.

If this heat is supplied by an electric current C amperes flowing through a resistance R ohms placed in the air stream, equation (13) becomes

$$W = \frac{C^2R}{Jst}, \qquad . \quad . \quad . \quad . \quad (14)$$

where J is, as before, the mechanical equivalent of heat in Joules per calorie. Alternatively, if V is the voltage drop across the resistance, we may write

$$W = \frac{V^2}{RJst}. \qquad . \quad . \quad . \quad . \quad (15)$$

In Callendar's instrument use is made of the relationship in the form of (15). In brief, the apparatus consists of a resistance coil JK (Fig. 73) of material having a constant resistance, made in the form of a mat extending over the cross-section of the airstream to be measured, so that the latter is uniformly heated.

The temperature rise is measured by means of two resistance thermometers BD and EC, consisting of grids of fine platinum wire placed at equal distances on either side of the heating mat. These thermometers form part of the Wheatstone bridge circuit BACEFD, in which F is the balance point when no current is passing through the heating grid, i.e. when both thermometers are at the same temperature. When the air current is flowing in the direction shown, and the grid is heated, EC is hotter than BD and its resistance is higher. A new balance-point may be obtained at H on a slide-wire resistance

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*C. C. Thomas. *Journ. Franklin Inst.*, vol. 172, 1911, p. 411.

Moss and Stern. Aeronautical Research Committee—Engine Sub-Committee Reports, No. 55, Sept., 1920.

between D and E. The resistance FH is made equal to the difference in resistance of the two thermometers when their temperatures differ by a fixed amount—$2\frac{1}{2}$° C. was used in an actual case—and the heating current through the grid JK is adjusted to maintain this temperature difference constant, i.e. to keep the bridge BACEFD balanced. In equation (15) we then have the numerator constant, so that W varies as V^2.

The voltage drop across the heating grid, which is thus a measure of the wind speed, is determined by an arrangement similar to the volt-thermometer previously described. The leads from the terminals JK of the grid are connected to a second Wheatstone bridge SLTRP, of which the arms SL and LT are equal resistances, having zero temperature coefficient. The arm TR contains the volt-thermometer M, which is, as before, simply a fine platinum wire enclosed in a box, whilst N is a balancing resistance. PR is a potentiometer wire, to any point of which the connection of the galvanometer G_2 may be made. Instead of calibrating the bridge in terms of the distance of the balance-point from P when known voltages are applied, the rate of air flow may be correlated directly by calibration with the position of the balance-point. The method of operation in taking an observation is to adjust the rheostat in the heating circuit of JK until the galvanometer G_1 indicates balance of the thermometer bridge with the connection at H, and then to find the balance-point for the galvanometer G_2 on the potentiometer PR.

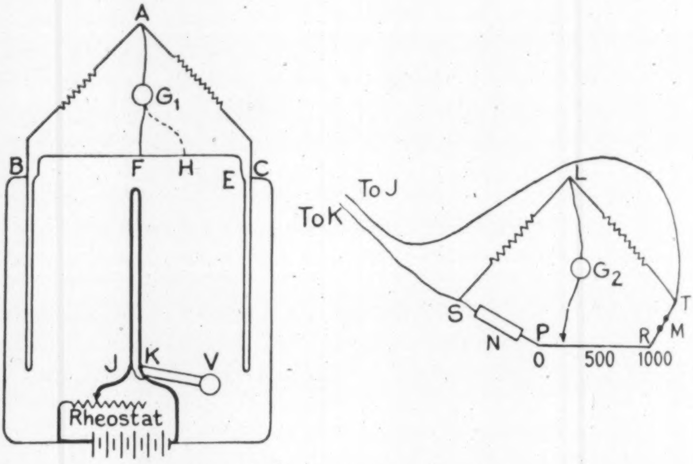

Fig. 73.

Complete descriptions of the instrument and of measurements conducted with it are given in the paper quoted in the bibliography, and reference may be made to this source for further details.

In the Thomas meter * a similar arrangement of heating and thermometer coils is used, but in this case the power supplied to the heating circuit is measured directly on a wattmeter. In an automatic form of this instrument, which has been put on the market for commercial use, an ingenious device is introduced to avoid the necessity for adjusting the current through the heating coil by hand, in order to maintain the thermometers at a constant temperature difference. By means of an electric motor drive, the needle of the galvanometer in the thermometer bridge is clamped between contacts at regular intervals of a few seconds. If the temperature difference is not at its prescribed value when one of these periodic contacts is made, the galvanometer needle will be off its zero position and a relay circuit is made which automatically varies a rheostat in the heater circuit, and so increases or decreases the current in this circuit, according to whether the temperature difference is too low or too high. The amount by which the resistance is varied is made to depend upon the deflection of the galvanometer in the bridge circuit, that is, upon the amount by which the temperature difference between the two thermometers has deviated from its standard value.

The Kata-Thermometer.—In the course of his researches on atmospheric conditions as affecting health and industrial efficiency, Dr. Leonard Hill designed an instrument known as the Kata-Thermometer to measure the rate of heat loss of a surface at approximately body temperature with variable atmospheric conditions. This instrument, which depends in principle upon the rate of cooling of a hot body, is essentially a specially designed alcohol thermometer. The bulb consists of a cylinder, 2·2 cms. in length and 1·8 cms. in diameter, with hemispherical ends, the total length being therefore 4 cms. Leading from the top of the bulb is a stem upon which is marked the range of temperature 100° F. to 95° F. The bore of the stem is enlarged at its upper end, so that the instrument may be heated considerably above 100° F. without risk of fracture.

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* C. C. Thomas. *Journ. Franklin Inst.*, vol. 172, 1911, p. 411.

Moss and Stern. Aeronautical Research Committee—Engine Sub-Committee Reports, No. 55, Sept., 1920.

Hill, Griffith, and Flack. *Phil. Trans. Roy. Soc.*, B., vol. 207, 1916, p. 186.

Hill, Vernon, and Hurgood-Ash. *Proc. Roy. Soc. Med.*, B., vol. 93, 1922, p. 198.

Angus. *Journ. Industrial Hygiene*, vol. 6, 1924, p. 2.

See also Medical Research Council, Special Report Series, Nos. 32 (1919), 52 (1920), and 73 (1923)

If an instrument of this kind is heated and then allowed to cool, the same amount of heat will always be lost whilst it cools over the range of temperature of 5° F. marked on the stem, but the rate of heat loss will depend upon the atmospheric conditions. It has, in fact, been found that if the kata-thermometer is exposed to a current of air moving with speed V, the mean rate of cooling over the temperature range, if the bulb is quite dry, is related to the air speed. The law takes the form

$$H = (a + b\sqrt{V})\theta, \qquad . \quad . \quad . \quad (16)$$

where a and b are constants,

θ is the mean excess temperature of the kata-thermometer over the surrounding air, and

H is the total heat lost in cooling from 100° F. to 95° F., divided by the surface area of the bulb in sq. cms., and by the cooling time.

It will be noted that this law is of the same form as that found by King for heated wires.

The total heat lost in cooling over a given range of temperature, although constant for a given instrument, will vary from one kata-thermometer to another. Despite the fact that it is endeavoured to make all instruments to a given size, slight variations in heat capacity still occur between different instruments. Each kata-thermometer is therefore calibrated in still air by the makers, and is given a " factor " F, which is the total heat lost in milli-calories per square centimetre of bulb surface, in cooling from 100° F. to 95° F. In order, therefore, to calculate H in equation (16), it is only necessary to observe the time T in seconds taken by the alcohol column to fall from the 100° mark to the 95° mark, and to divide the factor F, which is always stated on each instrument, by this time.

From a large number of experiments conducted with different kata-thermometers, the constants a and b in equation (16) have been determined. When V is expressed in feet per minute, and temperatures are measured on the Fahrenheit scale, this equation becomes

$$\frac{F}{T} = (0{\cdot}11 + 0{\cdot}016\sqrt{V})(97{\cdot}7 - t) \qquad . \quad . \quad (17)$$

for values of V less than 180 feet per minute,

and $$\frac{F}{T} = (0{\cdot}07 + 0{\cdot}019\sqrt{V})(97{\cdot}7 - t) \qquad . \quad . \quad (18)$$

for values of V above 180 feet per minute.

In these equations T is the observed time in seconds for the alcohol to fall through the standard temperature range, and t is the atmospheric temperature in degrees Fahrenheit.

Although these relationships are supposed to be general for all kata-thermometers, until the results of further work have been published upon the use of these instruments in anemometry, it would seem to be desirable, for the best accuracy, to calibrate each instrument separately. The calibration can be easily performed by the method mentioned in connection with the constant resistance hot-wire anemometer. Thus, a in equation (16) is given by the value of $\frac{F}{T}$ in still air when $V = 0$, and b can then be determined by a calibration at a single known air speed, although it is preferable to estimate it for a number of speeds and to take a mean value.

The procedure in using this instrument as an anemometer is as follows: It is convenient, if a number of observations have to be made, to start work with a vacuum flask filled with boiling water, in order to provide a ready means of heating the kata-thermometer to a temperature of over 100° F. The bulb of the kata-thermometer is placed in the water and is allowed to remain there until an unbroken column of alcohol fills the stem and about half the small bulb at the top of the stem. The instrument is then quickly removed from the water, carefully dried—this point is important—and then introduced into the airstream to be measured. When in this position, the kata-thermometer must be fixed to prevent swaying, and the bulb must be freely exposed to the current. An observation of the time of cooling over the standard temperature range is then made. The inventor states that this process should be repeated four or six times, according to the agreement obtained between the different observations. It is frequently found that the first reading differs quite widely from the rest, and it should always be neglected, the mean value of the cooling time being calculated from the remaining observations. The temperature of the air is observed during the tests, and equation (17) or (18) can then be used to determine V.

Approximate corrections for variations of air density may be applied on the assumption that, as in the case of the hot-wire anemometer, the heat loss is dependent upon $\sqrt{V\sigma}$, instead of $\sqrt{V}$ only, so that equation (16) may be written

$$\frac{F}{T} = (a + b\sqrt{V\sigma})\theta,$$

where a and b have the appropriate values given above.

The method of making these corrections has already been indicated in the discussion of the hot-wire anemometer.

NEW INSTRUMENTS

Recently Developed by Instrument Manufacturers

Write Information Section, Instruments Publishing Co., Pittsburgh, Pa., for additional Information.

Portable Hardness Tester

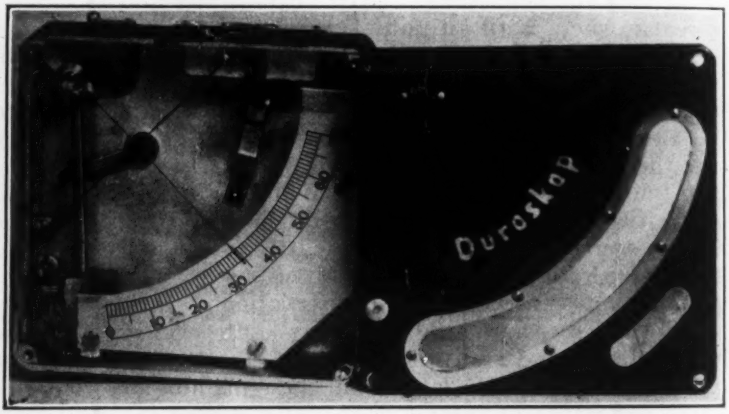
(R.Y.Ferner Company)

A NEW type of hardness tester which uses the principle of a falling pendulum. This instrument has the great advantage that it is portable so that it can be taken to the work and avoid the necessity of taking all the pieces to be tested to the apparatus.

Tests with this instrument, which is called the Duroskop, can, moreover, be made very rapidly since the entire procedure consists of holding the Duroskop against the piece to be tested and pressing a button on the back of the case which releases the pendulum to allow it to fall. The pendulum strikes through a hole in the edge of the case against the workpiece and, in rebounding according to the hardness of the piece, it carries with it a light pointer which remains at the highest point on the scale to which the pendulum rises.

The pointer, which is pivoted at the center of the arc of the scale, is lightly prevented from shifting by a wire stretched across the pointer which presses down on the pointer slightly and causes it to rest also against the edge of the scale over which it moves.

When a reading has been made with the instrument the pendulum is readily restored to its upper position by turning a spring-actuated lever. A leaf spring engages and holds the pendulum ready for the next test.



The pendulum, in being raised to this position, picks up and carries along the pointer to the upper end of the scale. The section of the scale just beyond the 70° mark is bent upwards, however, and when the pointer reaches this inclined surface it is raised out of engagement with the pendulum and can be quickly brought back to the zero position by a lever on the front of the instrument case.

Crossed V-grooves in the edge of the instrument which is placed against the workpiece permit setting it properly against cylindrical pieces in either a horizontal or vertical position. The instrument is, in fact, especially useful for checking case-hardened rollers. Exact adjustment of the instrument is easy with the aid of a built-in level on the top of the case.

When necessary the instrument can be placed on top of the workpiece and the pendulum is allowed to fall and strike the upper surface of the piece. The readings obtained in this way are lower than when the instrument is held against the side of the workpiece, but they can be converted to the usual readings by means of a curve.

The deviation of the apparatus is at most only 0.5°, so that, from test results deviating slightly on different pieces, the different quality of the material in the pieces can be decided correctly.

The Duroskop has the distinct advantage over some other hardness testing instruments of practically not marring the surface of the piece being tested. It usually requires the use of a hand glass to detect the point at which the blow was struck. Because of this it can be used for the testing of ceramics as well as metals. It has also been found very useful in testing rubber products, linoleum, paper board, vulcanized fiber, roof tiles, graphite, concrete pipe, wood, etc.

In the metal industry uses for the instrument will readily be found in machine shops, rolling mills, steel plants, tool, gun and ball-bearing factories, railway shops, automobile plants, machine shops, tool rooms, heat treating plants and repair shops. Examples of pieces on which it has been used to advantage include cross-head tracks, cylinders, valves, pistons, piston rings, crank shafts, pins and rods, cutting tools and even very thin material, less than 0.002″ thick, can be successfully tested.

One valuable use of the Duroskop is the rapid checking of incoming or outgoing raw materials or of pieces that have been sent to a heat treating plant. It can also be used by the workman during the process of heat treating and in this use offers protection against needless expense, breakage of material and delays and losses that often run into considerable money. It also is useful in the stock room in selecting the best piece of steel for a given requirement.

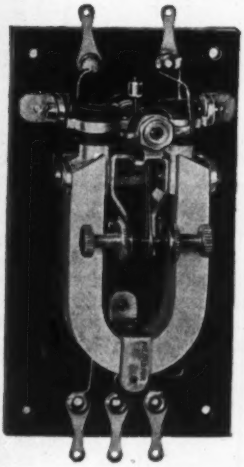
The instrument is complete in itself, having no gadgets to be carried about and attached. It weighs about 13 ounces, and is 4⅛″ square and 1¼″ thick so that it will easily slip in one's coat pocket.

Direct Current Milli-Volt and Micro-Ampere Relay

(Etna Electric Works)

THERE are 2 moving coils, these are supported by a central hardened pivoted shaft, which is held between the poles of a powerful permanent magnet by bearings of sapphire jewels mounted in screws.

On the central shaft there are mounted 2 spiral springs and the center contact bearing arm; these serve to conduct the applied current to the coils and to the arm bearing the central contact point. They also serve to set the position of the arm in relation to the side adjustable contact screws. An additional spiral conducting spring is employed when the operating current and the relayed current demand an entire separate circuit. At the side of the arm carrying the moveable coils an adjustable spring is engaged to regulate the movement of the coils at the required current value. The operating current, passing through the coils, excites a polarity adjacent to the magnet poles in such a manner that one coil is repelled while the other is attracted. Reversing the current will cause an opposite movement of the coils. The balanced moving element permits a sufficient degree of adjustment to allow for a delayed time operating feature.



The resistance of the relay coils may measure a few ohms, or as high as 1500 ohms depending on the number of turns of wire per coil, and may vary from 10 to 2400 turns depending on the current value required to operate the relay, which may be as low as 100 micro-amperes. Lower operating values are furnished on request. The contacts are of carbon or any metal desired may be used. The torque is sufficient to permit 250 milli-amperes at 80 volts.

The application to which this relay is especially adopted will cover a wide field, particularly when extremely small current values are involved.

In cells of the photo-electric type, and other light sensitive cells, or where current is derived from thermo-couples, this relay may be conveniently used to operate an amplifying stage or another relay. As a protective medium against excessive current, in connection with expensive delicate electrical instruments, this relay may be used to open or shut the circuit.

When used as a voltage regulator on battery charging outfits an external or self contained resistance is used.

Steam Flow Controls Feed Water Flow

H. M. Hammond*

IN ORDER to provide adequate feed water control for modern steam generating units having relatively small drum water storage capacity and where rating changes are often very rapid, a quick-acting feed water control system is imperative.

During recent years, higher boiler pressures, smaller boiler drums, the extensive use of water-cooled furnace walls, higher rates of steaming, rapidly fluctuating loads and the more common use of fuels burned in suspension, such as pulverized coal, oil and gas, permitting almost instant changes in rate of steam generation, have all contributed to complicate the feed water control problem.

Within the past 10 years the amount of water storage in a boiler has been reduced from approximately 1 lb. to 0.2 lb of water/lb. of steam generated per hour at maximum rating. Furthermore, the modern unit with water-cooled furnace walls has only about ½ as much of its water storage in the drum as compared with the average boiler of 10 to 15 years ago. Due to this change in relative water storage capacity of boiler drums, it would only require about 1½ to 2 minutes to evaporate all the water out of a modern boiler drum if something should happen to the feed water supply when operating at maximum rating. Such a unit permits a feed water control only about 1/10 the time in which to function upon a change in condition, as compared with the older boilers.

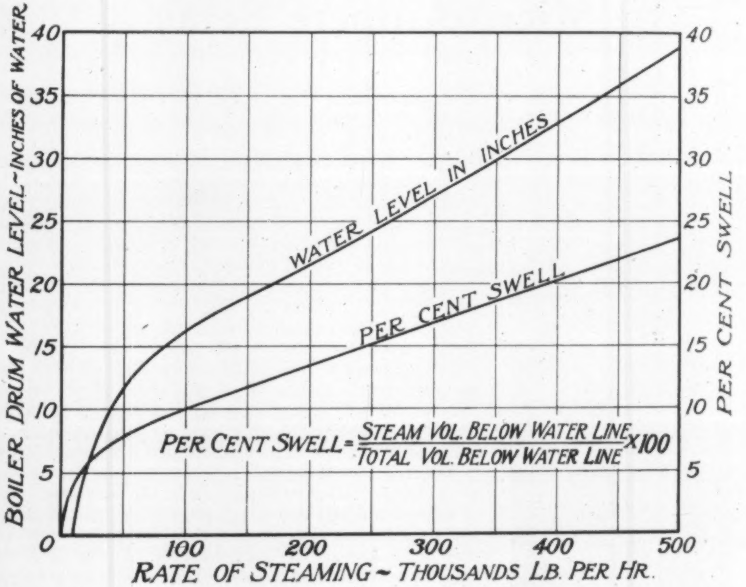


Fig. 1. Boiler Water Level vs. Rating for 2600 H. P. Cross Drum Boiler equipped with water cooled furnace walls and with constant weight of water in boiler (86,000 lbs).

With the increased rate of steaming of modern boilers, a very much greater percentage of the volume below the surface of the water is occupied by steam. This was found to be approximately 24% in the case of a 2600 H.P. cross drum boiler equipped with water-cooled furnace walls, as indicated by the curves in Fig. 1. Since only 15 to 20% of the total volume of water in a modern boiler is within the drum at normal water levels, it is evident that the drum water level will be seriously affected by changes in the rate of steaming. Feed water control for boilers of this type cannot operate very successfully in the ordinary manner from

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*Manager Sales and Engineerig, Bailey Meter Co.

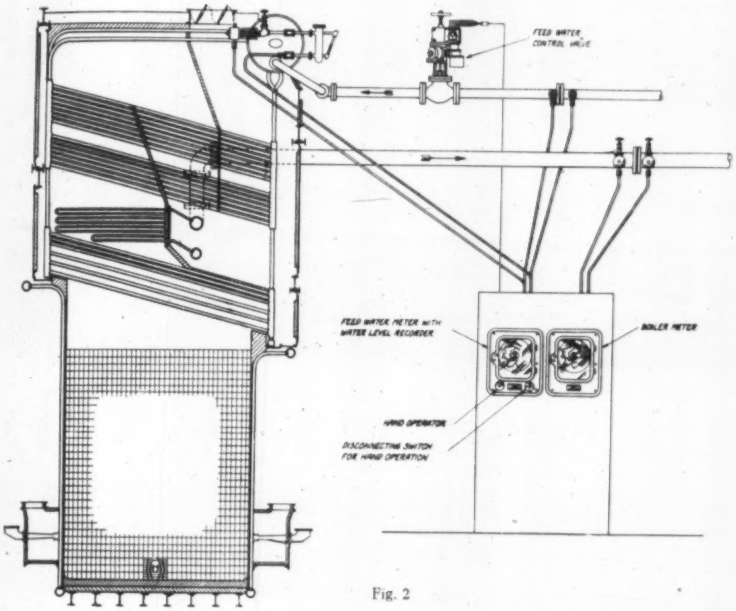
FEED WATER CONTROL VALVE
FEED WATER METER WITH WATER LEVEL RECORDER
BOILER METER
HAND OPERATOR
DISCONNECTING SWITCH FOR HAND OPERATION

Fig. 2

an indication of level alone, due to the fact that the water level is not a correct indication of the actual quantity of water in the boiler. A feed water control for boilers of this type must be extremely fast in operation to keep the level within normal limits during large changes in load. In some cases, the only possible way to maintain the water level within safe operating limits is by means of a control which will maintain a high water level at high boiler ratings, thus providing increased storage so the level will not drop below the water wall tube connections or below the drum when "shrinkage" takes place following a reduction in steaming rate.

Extreme variations in level may be caused by sudden fluctuations in load. An increase in load, for instance, resulting in a slight drop in steam pressure is immediately followed by increased steam generation due to the heat stored in the boiler water. This will cause the water level in the boiler drum to rise momentarily due to the increased volume of the steam bubbles below the water level. A feed water regulator operating from water level alone will tend to close during such an increase in boiler rating. Similarly, a sudden decrease in load will result in a drop in boiler drum water level due to the decreased volume of steam bubbles below the surface of the water. This will cause a so-called "single-element" feed water regulator functioning from water level to increase the flow of water to the boiler. Such a regulator is likely to hunt with fluctuations in the rate of steaming, and is therefore unsuited for controlling feed water flow to a large boiler unit generating high pressure, high temperature steam and operating at several hundred per cent of rating.

A "3-element" feed water control system has recently been developed to meet the stringent requirements of present day boilers. The 3 elements from which this control is operated are steam flow from the boiler, feed water flow to the boiler and water level in the boiler drum. In order to nullify the effect of "swell" and to maintain the rate of feed water input more nearly equal to the rate of steam output, this control functions primarily from steam flow but is modified slightly by water level when necessary, to hold the level within the desired limits.

The control is based on metered results as indicated in Fig. 2. A combined recorder for feed water flow and boiler water level, and an adjacent recorder for boiler steam flow, which may be the steam flow mechanism of the standard Bailey boiler meter, supplies complete operating information for boilers which require careful feed water control. The 3 elements of steam flow, feed water flow and boiler water level are coordinated by means of linkage, as indicated diagrammatically in Fig. 3, to operate a Selsyn sending device through a torque amplifier.

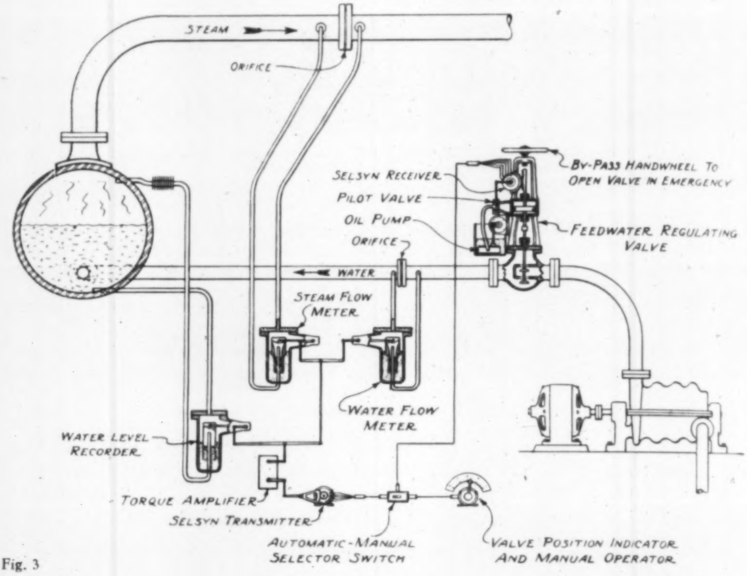
Steam
Orifice
By-Pass Handwheel To Open Valve in Emergency
Selsyn Receiver
Pilot Valve
Oil Pump
Orifice
Feedwater Regulating Valve
Water
Steam Flow Meter
Water Flow Meter
Water Level Recorder
Torque Amplifier
Selsyn Transmitter
Automatic-Manual Selector Switch
Valve Position Indicator And Manual Operator

Fig. 3

The linkage may be adjusted so that the water level in the drum is permitted to vary during normal operation, in accordance with the "swell" corresponding to the boiler rating. This insures maintaining a more nearly constant weight of water in the boiler instead of a constant water level. A low water level at low boiler ratings provides room for expansion with increased rating, thereby tending to eliminate the possibility of moisture carry-over. A correspondingly high boiler water level at high ratings also provides protection against a sudden loss of load with the consequent shrinkage of volume. Such an adjustment insures carrying sufficient water in the boiler drum to seal the water cooled furnace wall circulating tubes at all times. The system may also be adjusted to maintain a substantially constant water level in the drum at all times. This is usually desirable in the case of extremely high pressure boilers due to the fact that the specific volume of the steam approaches that of the water so that the "swell" becomes negligible.

The Selsyn method of electrical transmission is used as the connection between the flow meters, which are the primary source of control, mounted on the boiler panel board, and the feed water regulating valve. A torque amplifier, controlled by the movement of the connecting linkage between the three elements, turns the Selsyn sending unit at a rate proportional to the requirements for feed water. The receiving Selsyn motor, mounted on the flow regulating valve in the feed water line, accurately follows every movement of the sending Selsyn and in doing so moves a pilot valve in the flow regulating valve from its neutral position. This applies oil pressure to the proper side of the operating piston which opens or closes the valve to secure the required rate of flow. As the piston moves, the frame or stator of the receiving Selsyn is rotated in such a way that the pilot valve is returned to its neutral position and the flow regulating valve is held in the new position.

The Selsyn hydraulic feed water control valve, shown diagrammatically in Fig. 3, is provided with its own motor-driven oil-pumping unit mounted directly on the valve, resulting in a self-contained unit. This eliminates the necessity of extensive oil piping and the possibility of undesirable oil leakage.

While boilers operating at pressures from 1200 to 1400 lbs./in.^{2} do not seem to be troubled with level variations due to fluctuations in rate of steaming, the small drum volumes which, for economical reasons, are included with these boilers, require feed water control which is fast in action. The increased amount of power required to operate high pressure feed control valves and the decrease in sensitivity of ordinary methods of level indication with increased pressure, requires amplification of power between the level indicators and the valve. The Selsyn hydraulic system described, admirably meets these requirements by providing a control

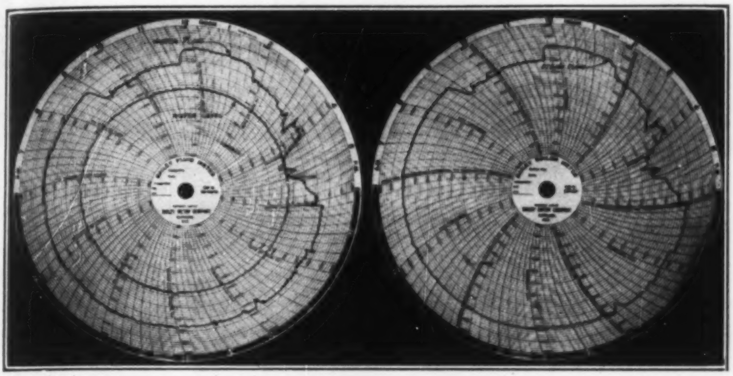

Fig. 4

which responds quickly and accurately to both small and large changes. Sufficient power is always available for operation of the valve.

A valve position indicator may also be placed on the operating panel board below the meters so that the operators may know the position of the feed water control valve at all times. A hand control is also incorporated which permits operation of the control valve independently of the automatic control. This only involves the operation of a switch, after which the valve may be positioned manually through the use of a knob on the valve position indicator.

A Bailey Three-element Feed Water Control Valve, designed for 1600 lb. pressure service is a fully-balanced tight-seating valve similar to the one used in the standard Bailey Thermo-hydraulic Feed Water Regulator. It has a valve cage which is easily removable for inspection or grinding and which is provided with ports to give a straight line flow characteristic.

Steam Flow and Feed Water Flow Meter charts representing the operation of this Selsyn Hydraulic Three-element Feed Water control are shown in Fig. 4. From these charts it will be noted that the feed water flow responds simultaneously to changes in the rate of steam flow. The boiler water level is held constant in this case, since this boiler operates at 1300 lb. pressure.

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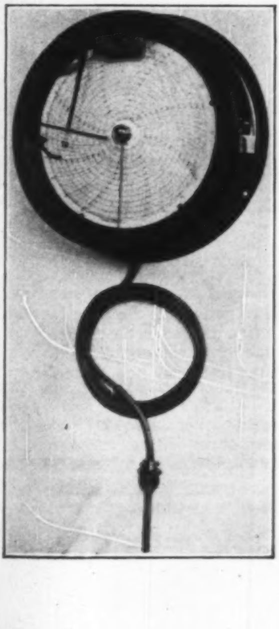


Anti-Ambi Thermometer

(*Foxboro Company*)

THIS new recording thermometer is claimed to give true bulb temperatures at all times irrespective of summer heat or winter cold. The case and tubing may be enclosed in a cabinet and the temperature changed rapidly or slowly up and down for 50° and the pen will remain perfectly steady. The thermometer is designed for use on temperature ranges up to and including 250°F.

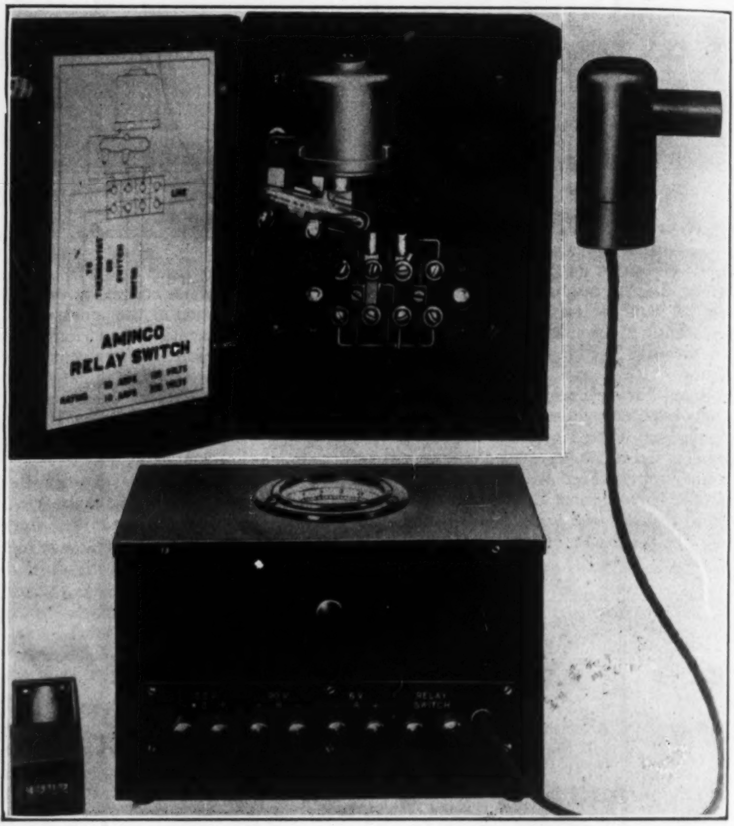
The instrument is unique in construction, being based on a new interpretation of an old and proved principle. It contains no cams, compensating levers, bi-metallic strips, nor retarding action of any kind.

A special construction feature is found in the small bulb. The thermometer is so designed that it can make use of a sensitive bulb as small as one inch long. This feature will be found very useful particularly in measuring temperatures in pipes.

Aminco Photoelectric Relay

(*American Instument Company*)

THE essential elements of this device are a photoelectric cell with housing, vacuum tube amplifier, sensitive relay, lamp, and necessary connections.



Light falling on the sensitized surface of the photoelectric cell varies the resistance to the flow of current through the cell. If the cell is connected in the grid circuit of a vacuum tube the grid potential will vary as the light intensity varies, and consequently the plate current will increase or decrease. If the plate current is passed through a milli-ammeter the readings of the milli-ammeter will indicate the intensity of the light falling on the photoelectric cell. If again the plate current is passed through a sensitive relay, the relay may be adjusted to go on or off at a given light intensity, and thus operate the Aminco Relay Switch or other device.

The device may be used for:

Counting bags, bales or boxes on a conveyor.

Counting vehicles passing a given point in a given time or continuously.

Counting insects, such as bees, entering or leaving a hive, or articles too small or too light in weight to operate a mechanical contact or counter.

Counting freshly painted objects.

As a check on turnstile operators admitting persons to amusement parks, subway entrances, etc.

As a frictionless contact on master pendulums.

For stopping machinery where the product ceases to come off in a steady manner, such as broken paper in a paper machine.

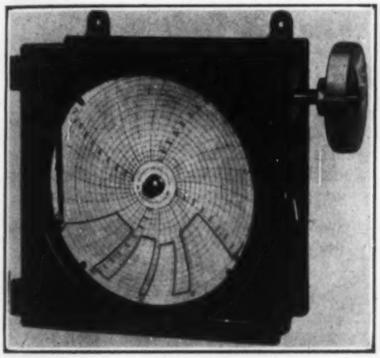
As a safety switch on punch presses or other machines where presence of operator's hands or body will interrupt beam of light and thus prevent operation of machine.
As a door opener for persons with arms full, such as waiters and waitresses.
Deflecting packages into selective chutes, such as mail bags or bundles.
Timing races.
For controlling traffic lights at points of varying congestion.
To turn on and off street and interior lighting at sunset and sunrise.
For an additional safety device on elevators to prevent operation while doors are open.
To ring an alarm if a safe door is opened after the device is set for signalling.
As a smoke detector.
For measuring turbidity, smoke intensity, sorting according to color or reflecting power.

To put the instrument into operation it is only necessary to place a light of suitable intensity opposite the photoelectric cell. The relay can be arranged to go on or off with any interruption of the light and its sensitivity can be changed so that a slight increase or decrease in intensity will operate it. The side outlet on the photoelectric cell housing insures that no light but that intended shall fall upon the cell.

New Operation Recorder

(Amthor Testing Instrument Co., Inc.)

THIS operation recorder makes it possible to check and trace the basic causes for production loss of practically any periodically moving machinery. On an 8" chart it automatically records and supplies a continuous visual picture of the entire operation of the machine on which it is installed. It shows the speed or rate of production at any time and every change in speed. It shows all starting and stopping times, all slowdowns, non-productive periods, the time and duration of each, and the actual producing and idle time. The chart can be graduated directly in r.p.m. or in any unit of production which is a function of or depends on the speed or rate of production of the machine; as in "feet per minute," papers per hour, etc.



The recorder movement is based on the centrifugal principle which affords a powerful and uniform action. The motion of the governor is transmitted directly to the pen arm by connecting links. Direction of rotation has no effect upon the governor mechanism as the movement of the pen arm is not reversed if direction of rotation is reversed. The entire moving mechanism comprises a few simple parts. Action is purely mechanical. It is entirely independent of temperature change or mechanical influence. The chart is driven by a standard clock movement to provide either a 12 or 24 hour record as specified.

Wear is eliminated by the use of precision ball bearings packed in grease and which require no lubrication beyond once a year. A highly perfected damping device takes up any undue vibration or shock and imparts a steady natural motion to the pen arm. The case of the recorder is fully moisture proof. For installation, either belt, coupling or flexible shaft can be used. For long-distance installation, cord and special overhead guide pulleys are provided.

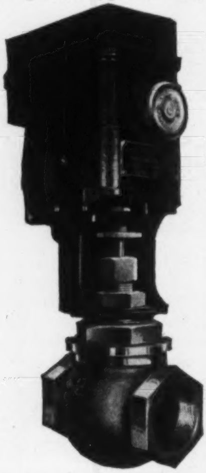
The recorder can be applied to any type of industrial plant machinery for purposes of either recording speed and operation, or to detect operating irregularities due to undetermined causes such as faulty driving arrangements, overload, etc. In addition to the continuous operation record provided, it also supplies more specific constructive data directly pertinent to the type of output or operation of the individual machine. For instance, on turbines it can be used to check the correctness of the overspeed or safety trip. On paper machines, to check and determine the exact speed for the given grades of stock. On rotary printing machines, to determine efficient operating schedules.

The fact that all these data are automatically detailed on one chart, showing machine operation and rate of production during the entire day, makes the recorder a dependable aid to the business or production manager and enables him to increase operating efficiency, lower production costs, and enforce a strict observance of schedules.

New Design Motor-operated Valve

(*Automatic Temperature Control Co.*)

THIS new controller is shown mounted with a single seated globe Type GS valve as supplied for high-pressure gas using inspirator type burners. For low-pressure gas using inspirator type burners, a butterfly Type BP valve is available, while for steam or water at pressures up to 250 lbs. a tight seating globe Type GSP valve having single seated pilot is recommended.



On gas-fired installations, by-pass piping and by-pass hand valves can be eliminated as provision is made at the control valve for minimum fuel supply. The controller will function reliably when mounted in any position, hence its valve may be located in either a vertical or a horizontal pipe line as found more convenient.

A screw shaft geared to the motor imparts straight line motion to the operating yoke and by means of this yoke, a valve can be operated from closed to open position within two seconds time.

Positive valve positioning is assured with this unit as declutching takes place before the motor comes to rest. This novel design of power transmission prevents any possibility of the valve jamming or sticking at either extreme of its stroke.

A fractional turn of the motor shaft operates a transfer switch built into the controller, hence only momentary contact is required at the actuating instrument and as the motor starting current is but .15 amperes, no relay is required—even when the contact instrument is subjected to vibration.

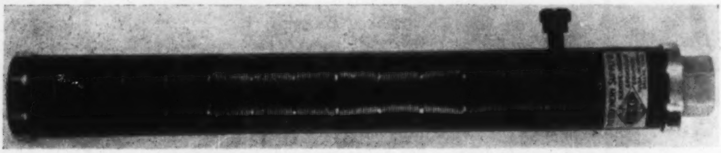
◆

R. S. Gas Leak Detector

(*Refinery Supply Co.*)

THE gas leak detector consists of a gas-burning chamber, in the front of which is a window graduated in inches, from 0 to 12. This window is covered with miners' safety lamp screen, so that the flame within the chamber is visible yet cannot endanger the operator.

Gas in the chamber is ignited by means of the lighter, which is operated by simply turning an ignition knob on the outside of the burning chamber.



The orifice through which gas enters the chamber is protected by a screen fire check, abolishing any hazard of fire or explosion—making the detector 100% safe.

In operating the detector, a pipe is inserted into a test bar hole to a depth of approximately one foot, extending about two feet above ground. At the upper extremity of the pipe a gate valve is connected. Immediately above the gate valve the detector is attached.

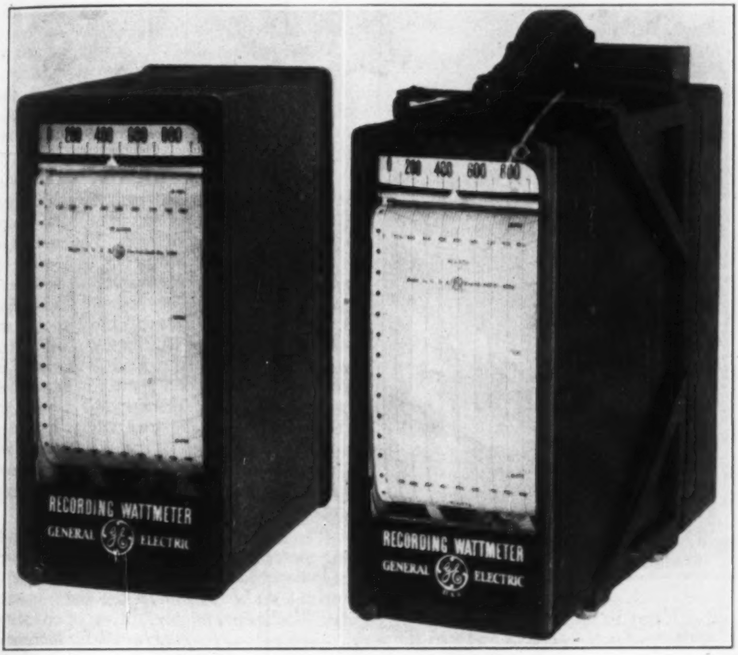
To prevent the escape of gas, the hole around the pipe is closed by means of damp waste or a rubber force cup.

Rotating the ignition manipulator causes a flint to spark, igniting any gas which may have entered the burning chamber through the intake orifice.

The amount of gas at the test location is indicated by the scale. Naturally, the highest point of flame recorded on the scale identifies the point nearest the cause or source of the underground leakage.

Improved Recording Instruments

SEVERAL changes in its strip chart recording instruments, Type CD, have been announced by the General Electric Company. The chart reroll unit is now separate and spring-driven, releasing the clock of all duty except keeping time. Only 2 turns of a thumbscrew are required for fastening or removing the cover of the instrument. The clock is completely enclosed. Either a Warren synchronous motor or a spring-clock movement affording 9 days' operation is provided, at the option of the purchaser.



The terminal block on the portable model is tilted 30°, allowing use of a screw-driver from the front. Indicating scales, standard equipment in addition to the charts, are removable and interchangeable. The chart speed of portable types can be changed readily from inches/hour to inches/minute by means of a gear-shift lever, without removing the cover. Another lever is used for starting and stopping the clock. An automatic locking device prevents the reroll spring from running down when the used-paper roll is removed; and an automatic brake for the roll of supply paper balances the pull of the reroll, prevents pulling the paper off the driving sprockets or overrunning the clock, and permits accurate timekeeping.

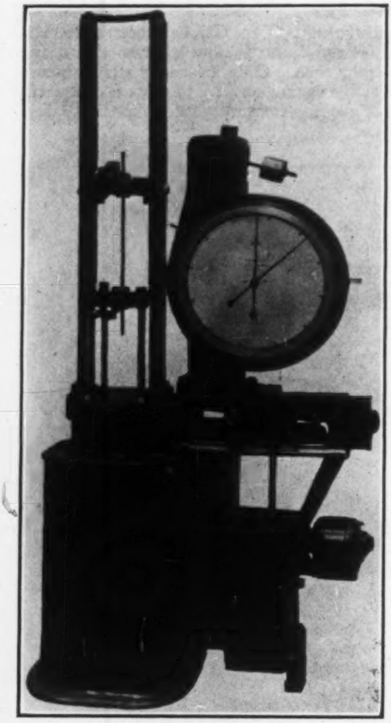
The Type CD recording instruments are available for d.c. or a.c. operation, and for portable or either front- or back-connected switchboard mounting. The switchboard instruments can be mounted on 5½ inch centers.

◆

Hydraulic Type Universal Testing Machine

(Tinius Olsen Testing Machine Co.)

THIS machine combines flexibility of hydraulic loading system with convenience of dial reading. The dial is mechanically operated under control of levers and a pendulum which is a reliable primary weighing system. The dial is large and the pointer can make two



complete revolutions, providing equivalent of two dials in one, and enabling operator to read correspondingly small increments of load.

The loading system consists essentially of a hydraulic cylinder and piston located in base of machine; the piston being connected to the four straining rods shown attached to and terminating at the moving crosshead gripping the lower end of tension specimen. As pressure is increased in the hydraulic cylinder the lower crosshead moves down, tension load is applied through specimen to upper adjustable crosshead and then downward through the two side columns to the weighing table which does not touch the four straining rods or any part of the straining system.

The weighing table rests on knife edges in levers. Through a system of levers the load is transmitted to a pendulum on back of upright housing at rear of dial. The amount of movement of this pendulum is shown by pointer on dial which is marked so as to read direct the number of pounds load being applied to test specimen. On the dial are two pointers, one of which moves forward or backward constantly as load is increased or reduced. The second pointer is drawn forward by the first pointer and always indicates the maximum load which has been applied to specimen. The yield points are thereby shown clearly and when specimen breaks the second pointer remains at breaking load until set back by the operator.

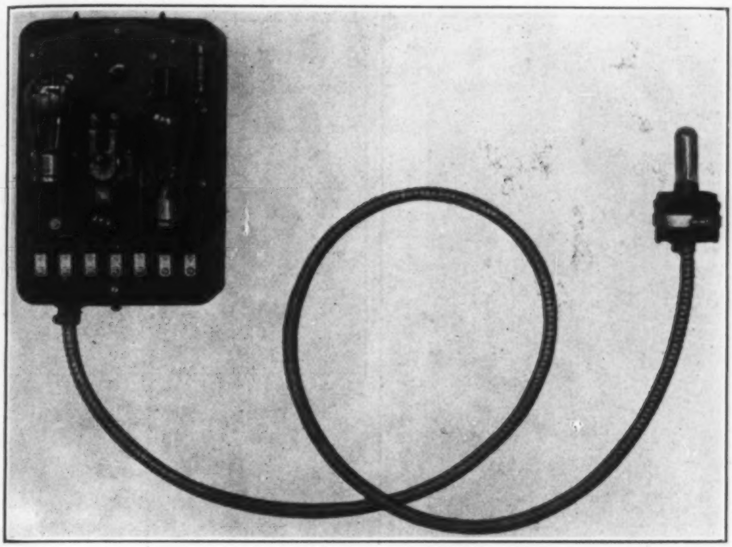
The knurled handle on front of lever housing controls stop or up and down movement of lower crosshead. The knurled handle on top of lever housing under the dial is marked so that it may be set at various positions to regulate "inches per minute" travel of crosshead up or down at various speeds. Automatic regulation is provided so that as load is increased, the rate of travel of crosshead is maintained. When specimen breaks provision is made for quick return of crosshead to top of its stroke where it is ready for the next test. The machine has direct motor drive and is practically noiseless in operation.

◆

Photoelectric Relay for High-Speed Operation

A HIGH-SPEED photoelectric relay, designated CR-7505-G-5, has been introduced by the General Electric Company as an addition to its line of electron tube control equipment. This device uses a Thyratron tube as a relay and finds its application in those operations where speed would be a limiting factor were a mechanical type relay used instead of the Thyratron.

The device is expected to be of greatest value in two general types of service: (1) where the operation proceeds at unusually high speed and a relatively small amount of current is controlled by the relay; and (2) where the speed is less—although possibly still too great for a mechanical type relay—and it is required that a relatively large amount of current be interrupted. In the first class of service, the Thyratron tube would serve as a relay, while in the second, the tube would actuate a contactor. Among the suggested uses are the rapid sorting, selecting or registration of objects; high-speed counting; and other applications where the time for response is too short for a mechanical type relay operating on a small amount of current.



Three electron tubes are used: a photoelectric tube which picks up the light impulse and produces a corresponding electric impulse; a Pliotron tube which amplifies the electric impulse produced by the photoelectric tube; and the Thyratron tube which acts as a relay, producing properly timed impulses to operate electric devices either direct or through the medium of a contactor.

A small contactor is built into the complete device which may be actuated by the output of the Thyratron tube where necessary to control currents in excess of the rating of the Thyratron. A larger contactor may be added and controlled directly by the Thyratron tube. The device is built for operation on 110-volt, 60-cycle circuits.

* * *

Light Relay and Light Source Units

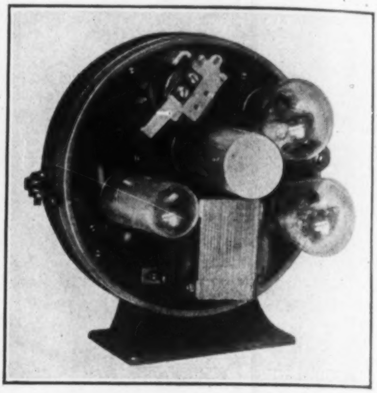
(Burgess Battery Co.)

THE Burgess A.C. Light Relay is designed to operate on the usual 110-volt A.C. supply. It consists of a Burgess Radiovisor Bridge feeding a 427 type vacuum tube as the amplifier, which in turn actuates a power relay. The circuit contains in addition a power transformer, filter condenser, necessary resistors and by-pass condensers. A second 427 tube serves as the rectifier.

In the case of the D.C. unit, intended for operation on the usual 110-volt D.C. supply, a bridge is employed, together with the newly perfected 430 type 2-volt tube, voltage reducing resistor, circuit resistors, by-pass condensers and power relay.

Both A.C. and D.C. light relay circuits may be arranged with open power relay contacts when the cell is in either light or dark condition, depending on the requirements of the desired application. The components are mounted on a circular platform enclosed in an aluminum housing which is supported by means of a ring bracket, the arrangement permitting of turning the unit to bring the bridge window in line with the actuating source of light. The circuit to be controlled is connected with the relay contacts. If the Burgess Vacuum Contact is employed with the relay, the unit will control equipment drawing up to 1320 watts, or 6 amperes at 220 volts.

For use in those situations where the light source must be artificially supplied, the Burgess Light Source units in both A.C. and D.C. models are available. Each light source unit employs a 12-volt 21 c.p. incandescent bulb, focused by means of an adjustable optical system upon the bridge of the companion light relay unit.

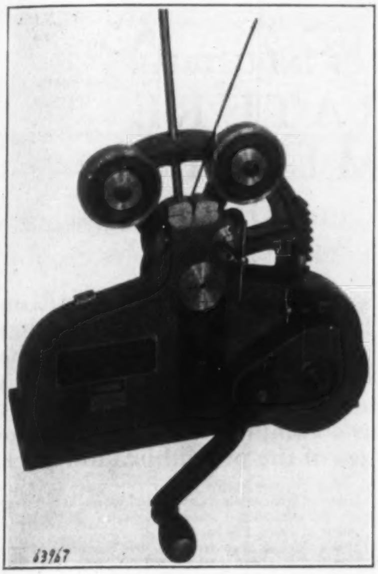


The light relay unit functions by the modification of the light that passes through its window and falls on the light-sensitive plate of the bridge. The variation in light causes a corresponding resistance variation in the bridge itself, thereby controlling the flow of current to the amplifying tube in the same circuit. The amplified difference in current flow causes the desired operation of the relay, which in turn closes or opens the circuit of the equipment to be controlled by light. The simplest application is the control of electric lighting systems, whereby the lights are turned on at nightfall, and turned off at daybreak, by purely automatic means. Another application is the counting of vehicles, packages, parts or other units which pass between light source and light relay, interrupting a beam of light. In this case the relay controls an electromagnetic counter, which keeps tally with automatic precision. Still another application is a burglar alarm, whereby an invisible beam of light, made possible by the use of a color filter in the light source, protects a doorway or room. Any interruption of the invisible beam of light actuates the light relay which in turn rings an alarm or otherwise makes known the presence of an intruder. Sorting is accomplished by causing any alteration to shadow or light intensity to upset a given balance in the light relay, actuating the desired apparatus. The light relay may be arranged to operate an automatic door opener when truck or person interrupts the light beam. Placed in a funnel, the light relay and companion light source give notice of the presence of smoke. A similar arrangement is employed as a smoke detector for fire alarm purposes.

Warner Reverse Bend Machine

(Tinius Olsen Testing Machine Co.)

OPERATION of the machine consists in bending a specimen back and forth over definitely shaped jaws so that smooth bending in opposite direction is alternately



effected. The machine illustrated herewith is intended for small rods and flat specimens and can be supplied in various sizes and types and either hand operated or motor driven.

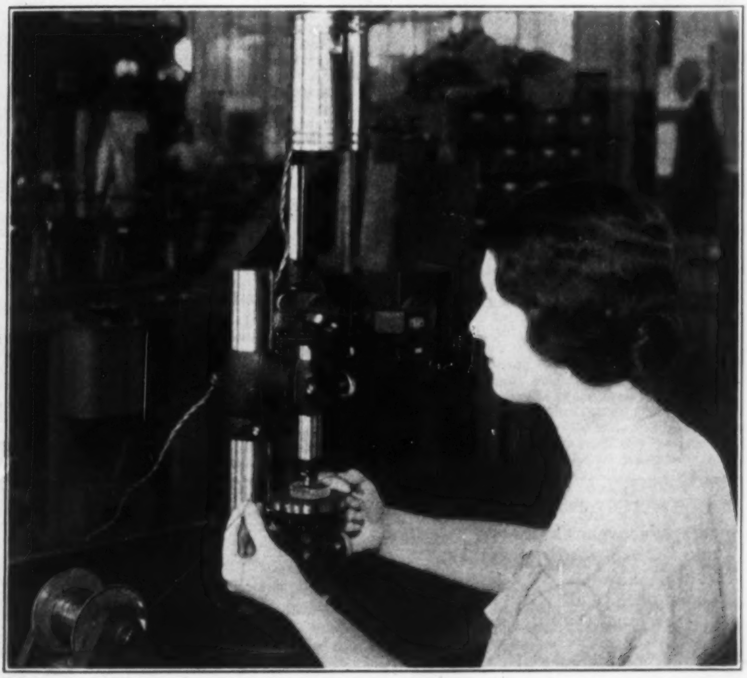
The jaws have a relatively small radius close to where the specimen is gripped. The two large rollers at top of machine are caused to oscillate back and forth and travel in a path parallel to the tops of the grip blocks in which the specimen is held.

Fast speed is effected in the hand operated machine either by operating with the bar at top of machine or with the hand wheel on the large gear at right side for slower speed and to provide more power for larger specimens the hand crank as placed on the pinion spindle as shown in illustration.

Counter just over the driving gear is provided to show the number of strokes required to break specimen.

Usually only a few strokes are necessary to break the specimen and the hand operated machine is quick and convenient for this purpose. Motor drive however, can be supplied for greater convenience or especially in the larger size where more power may be required.

* * *



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THE FOG HORN. The October, 1931 issue of this publication contains the article, "Ventilation for Human Comfort" by James Holt. Parks-Cramer Company, Fitchburg, Mass.

INSULATION TESTING SET. Cir. 5600-G describes an improved insulation resistance testing set for measuring the insulation resistance of present-day dielectric materials. Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia, Pa.

STORAGE BATTERY TRANSPORTATION. A tribute to Mr. Edison in terms of his life-time role of a teacher. Edison Storage Battery Co., W. Orange, N. J.

POTENTIOMETER PYROMETERS. 48-page Catalogue No. 1101 covers a new line of potentiometer pyrometers, with more than fifty advantageous features described. The Brown Instrument Company, 4482 Wayne Avenue, Philadelphia, Pa.

ELECTRICAL INSTRUMENTS. Catalogue F Part 3 completes Catalogue F. This part is devoted to electrical measurements at communication frequencies. General Radio Co., Cambridge A, Mass.

MEASURING INSTRUMENTS. Catalogue No. 437 describes and illustrates measuring instruments for laboratories and observatories. Catalogue No. 352-B entitled, Measuring Machine Universal Type and Simple Type. Other publications of the same company carry the following titles, Astronomical Instruments and Accessories, Apparatus for Testing Graduations on Circles; The Micro-Indicator Stand U-2; The Sip Micro-Indicator Type U-2; High Power Electro-Magnets for Laboratory Purposes; Industrial Thermal Analyzers and Differential Dilatometers, identified as Catalogue D-1; and Precision Pendulum Clocks, etc. The R. Y. Ferner Co., 1131 Investment Bldg., Washington, D. C.

CONSULTING SERVICE. A pamphlet covering the nature of the services rendered by the consulting chemist. Foster Dee Snell, Inc., 130 Clinton St., Brooklyn, N. Y.

DRAFT AND DISPLACEMENT INDICATOR. A circular marked Cat. Ref. 25 describes the "Teledep" draft and displacement indicators, for accurate measurement and instantaneous readings of ships' draft and displacement. Dobbie McInnes & Clyde Ltd., 57 Bothwell St., Glasgow, Scotland.

PHOTO-ELECTRIC RELAYS. Bulletins No. 875 and 880 are devoted to Light Sources for Photo-Electric Relays and Photo-Electric Relays. Allen-Bradley, Milwaukee, Wis.

TELEPOINT COMPASS. A circular describing the Telepoint compass, a new remote reading magnetic compass. Pioneer Instrument Company, 754 Lexington Ave., Brooklyn, N. Y.

THE GRAPHIC. No 831 features the article, "Time Recorders for Plant Supervision." The Esterline-Angus Company, Indianapolis, Ind.

WATER WORKS JOURNAL, contains some of the following articles: The New Kansas City, Missouri, 100,000,000-Gallon Per Twenty-Four Hour Capacity Water Purification Plant; Construction or Destruction; Hydraulically Speaking. Pittsburgh Equitable Meter Co., 400 Lexington Ave., Pittsburgh, Pa.

CONTROLLER. A circular describing a motor operated controller mounted with single seat, globe valve. Automatic Temperature Control Co., Inc., 34 East Logan St., Philadelphia, Pa.

RECORDING INSTRUMENTS. Bulletin No. GEA-1061D contains information on recording instruments of CD Type for alternating and direct current. General Electric Co., Schenectady, N. Y.

SEISMOMETER. A circular illustrating the seismometer equipped for electromagnetic damping and electromagnetic and optical manification. The R. Y. Ferner Co., Investment Bldg., Washington, D. C.

BRINE-O-METER. A leaflet describing the Brine-O-Meter, a salt tester. The reversed side of this leaflet describes a Calci-Chlor-O-Meter for testing calcium chloride. E. Edleman & Co., 2332 Logan Blvd., Chicago, Ill.

BAKELITE REVIEW. The October, 1931 issue of this publication features the article entitled, "It is Time to Weight the Consequences." Bakelite Corporation, 247 Park Ave., New York.

TECHNICAL INSTRUMENT BULLETIN. The September, 1931 issue contains an article entitled, "The Application of Reflected Light to the Microscopic Examination of Leather" by A. Kuntzel. Emil Busch Optical Co., Ltd. 37 Hatton Garden, London E.C.1, England.

INTEGRATOR. A booklet describing the EMCO-McGaughy Integrator, a development in office equipment designed to facilitate the calculation of the total extension of orifice meter charts. The Pittsburgh Equitable Meter Co., 400 Lexington Ave., Pittsburgh, Pa.

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CURRENT LITERATURE REVIEW

Abstracts on instruments and devices for measurement, inspection and control

The Technology Department, Carnegie Library, Pittsburgh, Pa., will furnish photostats of material abstracted here. Negative prints are 25 cents per page, plus 10 cents for mailing (first class). All orders should be paid in advance. The library is not responsible for loss in mail.

Notes on Audio-frequency Measurements. John K. Hilliard. Electronics, February 1931, pages 506-507.

Describes a portable equipment for making gain frequency measurements on studio field units and theater sound equipment. It comprises an oscillator; a power amplifier; a volume control; a power level indicator; a panel with input attenuators, keys, volume control and output termination for equipment under test; and the requisite impedance matching coils and jacks.—M. F. B.

Testing of Sound-picture Channels. G. F. Hutchins. Electronics, February 1931, pages 502-503.

Some of the important tests and instruments necessary to maintain a recording channel in perfect condition are outlined. The need of high quality instruments is stressed. Diagrams are given of especially applicable measuring circuits. Graphic curves showing correct line voltages to give desired level are given, representing various impedances. Calculations for meter setting are gone into.—M. F. B.

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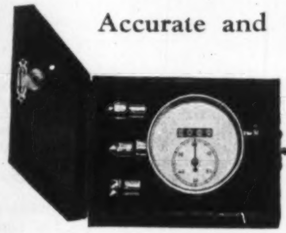

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INSTRUMENT DESIGN AND CONSTRUCTION

A New Drawing Apparatus (Ein neuartiges Zeichargerät). H. H. Neumann. Zsch. Feinmechanik und Präzision, Vol. 38, No. 24, Dec. 31, 1930, page 7.

Consists of a metallic, non-rusting L-shaped rule and a fine graduation on a disc of light metal which are both fastened to the T-square.—Ha.

New Types of Coin Meters (Neuausführvungen von Münzzählern). W. Bergmann. A. E. G. Mitteilungen, Mar. 1931, pages 140-144.

Describes new modifications. Some arrangements can also be attached to ordinary meters to convert them into pay-meters.—Ha.

A New Electric Self-Winding Clock (Eine neue elektrische Selbstaufzu gsuhr). F. Baltzer. Elekt. Zeitschrift, Vol. 52, No. 10, March 5, 1931, page 324.

The clock is wound by a small Ferraris-motor which is braked mechanically after the spring is wound up until the latter has made a full turn again. In this way the spring is utilized in the most uniform range of its force. A full description is given of the clock, which is made by Siemens & Halske, A. G.—Ha.

Universal Apparatus for Adjusting, Testing, and Aging of Thermometers with Electric Heating and Stirring Device (Universal-justier-and Prüfungs- sowie Alterungsapparat für Thermometer mit elektrischer Heizung und elektrischer Rühr ein richtung). Glas und Apparat, vol. 12, No. 4, Feb. 22, 1931, page 27-28.

This device can be used as water bath for low temperatures, as oil bath for 50 to 150°C, as oil bath for 150 to 390°C, as saltpetre bath for 300 to 500°C, for cold mixtures, and for aging of thermometers. The electric heating element can stand 1300°C. A switchboard carries the whole control arrangement. The device is made by G. Koechert & Sohne, Ilmenau.—Ha.

Amsler Circular Dividing Machine (Amsler Kreisteilmaschine). Zeitschrift Feinmechanik und Präzision vol. 38, No. 22, Nov. 30, 1930, pages 5-7.

Detailed description of construction and operation of the machine for which an accuracy of ±1/100 mm of the length of the arc is guaranteed. Weight 170 kg.—Ha.

Deflection Due to Temperature of Bi-Metallic Strips of Any Curved Shape (Temperaturausbiegung von Bimetallstreifen beliebiger Kurvenform). K. Becker. Forschung und Technik, 1930, pages 340-348.

The locus of the free end of a bi-metal strip which is clamped rigidly on one end and has any given shape is determined as a function of shape and temperature. The function is theoretically derived and simplified for the case of a small increase of temperature (initial deflection). The derived functions are evaluated for the straight strip, half-circle and full circle and the temperature-sensitivity is defined. The initial deflection and the temperature-sensitivity are calculated for one leg of a U-shaped strip, held in the U-point. This problem is often met with in practice, as these arrangements are used for thermal relays. An example is shown where a straight strip is heated until it assumes the shape of a full circle. Calculation and test show a close agreement.—Ha.

Pivots of Electric Meters (Les organes de pivotage des compteurs d'électricité). G. Grumberg Revue Générale de l'Electricité, Aug. 23, 1930, pages 273-282.

Describes a rapid method of testing pivots and jewels. The method consists in subjecting the pivot and jewel to a normal life-time service in a relatively short time of 10-20 hours. This means the application to the pivot of 1-4 million rotations at a suitable speed. Indicates how this speed should be evaluated for the conditions of operation of the system, without interruption during the test. Describes the apparatus used. Gives results of the examination of a number of photomicrographs, which allow accounting for the importance of wear. The influence of this wear on the meter readings is shown by curves indicating the errors. Discusses selection of jewels for meters and gives rules for the maintenance and repair of jewels for various types of meters.—M. S.

Finishing Industrial and Scientific Meter Parts. Thomas H. Wittkorn. Metal Cleaning and Finishing, Sept. 1930, pages 785-788.

Describes cleaning, enameling, and plating procedure of the Brown Instrument Co.—M. S.

New Meter Factory. Electrical Review, Dec. 5, 1930, pages 967-968.

Description of the equipment and operations at the plant of the British Sangamo Co., Ltd., for the manufacture of electrical meters.—M. S.

New Frequency Meter. C. L. Lipman. Electrical Review, Nov. 7, 1930, pages 793-794.

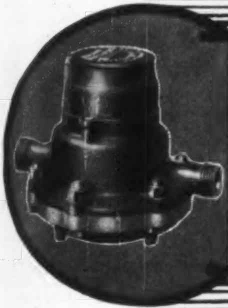
Describes a deflection type instrument which works on the induction system and consists of a fixed and a moving system. Fixed system comprises an external U-shaped electromagnetic carrying the primary and secondary windings, and an internal core of cruciform shape on two diametrically opposite polar projections on which are mounted two auxiliary coils. The moving system consists of a thick aluminum drum which is free to rotate in the air-gap between the poles of the external and internal electromagnets. The rotor is attached to a spindle which rotates between jeweled centers and carries the pointer and balance weight arms in the usual manners. Explains the electric and magnetic circuits and gives the advantages of the meter.—M. S.

A Fluxmeter with Counterbalanced Restoring Torque. F. E. Haworth. The Review of Scientific Instruments, February, 1931, pages 125-128.

A fluxmeter is essentially a galvanometer of very high critical damping resistance, used with a comparatively low resistance in the external circuit. Under such conditions the electromagnetic damping is very effective and the moving coil, after having been deflected, will return only very slowly to its central position. For certain types of measurement, it is desirable to use a fluxmeter in which this drift is completely neutralized. In the instrument described, the restoring torque of the suspension is completely counterbalanced over its useful range of deflections. A long, sensitive, photoelectric cell is fitted with a V-shaped slit; a beam of light is reflected from the mirror of the fluxmeter and focused on the slit of the photoelectric cell, which is connected, in series with a source of emf, across the terminals of the fluxmeter; the emf is adjusted to such a value that, if the beam is at rest when at the narrow end of the slit, at any other position the current controlled by the cell develops a torque in the fluxmeter coil which just balances the restoring torque of the suspension. Examples of curves taken with this instrument are given.—M. F. B.

The Mechanics of the Telescope. E. P. Burrell. Mechanical Engineering, April 1931, pages 255-261.

Because astronomical telescopes are instruments of precision of enormous size, they present a wide variety of mechanical problems. In this paper the Director of Engineering of the Warner & Swasey Co. first sketches the history of the telescope and then describes the principal types of telescope mountings. Problems encountered in foundations and in bearings are next dealt with. In somewhat greater detail the paper then takes up the problems of the polar axis, tube construction, the mirror cell and its supports, the driving clock (including means for retarding and for accelerating the slow motions in right ascension—setting motions for centering the image and following motions for maintaining the image as required), and electric control. Various accessories are also mentioned.—M. F. B.



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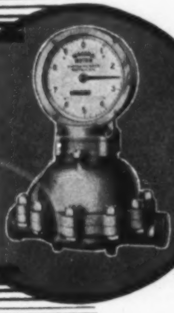

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A Simple Method for Leakage Detection in Glass Vacuum Apparatus (Eine einfache Methode zur Auffindung von Undichtigkeiten in gläasruen Vakuumapparaturen). P. Selenyi. Elekt. Zschr. Vol. 52, No. 11, Mar. 11, 1931, page 358, Zschr. Physik vol. 48, page 733.

The whole rarefied chamber is excited by Tesla currents and so shows the characteristic red luminescence. If then another gas, f.i. carbon-dioxide, is directed against the chamber, the red luminescence will pale at the leaky places and assume more or less the color of the other gas. Even very fine cracks can be discovered in this way.—Ha.

"Millibar," the New Barometer Scale ("Millibar," die neue Barometer skala). Th. Ziener. Glas und Apparat vol. 12, No. 4, Feb. 22, 1931, page 25-26.

Explains the new barometric scale for air pressures which has been generally accepted at the Meteorological Convention in Copenhagen in 1930, according to which the average air pressure at sea level of 750.09 mm is called one bar. This bar is subdivided in the same way as kg into 1000 millibars. This new division fits into the c.g.s. system, one bar being the pressure of 1 kg on 1 sq. cm. It is recommended in the future to calibrate all barometer scales in millibars. A conversion table from 600 to 800 mm into millibars is given.—Ha.

The Methods for Determining Size of Particles of Dusts (Die Verfahren zur Korngrössenbestimmung von Stäuben). O. M. Faber. Die Messtechnik, Vol. 6, Nov. 1930, pages 295-298.

From the dust-laboratory of the Bergakademie Clausthal. The methods for determining the diameters of dust particles are reviewed and their advantages and disadvantages discussed. Microscopic evaluation is very seldom satisfactory; the sieve-analysis cannot be used for all materials and is not applicable for dimensions below 60μ. Of all the instruments for this purpose, the flocculation meter of Wiegand-Gessner has proved to be the most convenient and accurate. In it the dropping time of dust particles of different diameters in distilled water is determined by the formula $K = 2/9gx(S-s)/y$ in which g = acceleration of gravity; S = specific gravity of the dust; s = specific gravity of the liquid; y = friction coefficient of the liquid (for of $20° = 0.010$), in g per cm. per sec.; K = constant from Stokes' formula, $C = 1/K$; $y = C\,H/t$ or $t = C^2H/r^2$; H = dropping height of the dust in cm; r = radius of the particle in cm; and t = dropping time in sec. 21 bibliographical references supplement this article.—Ha.

A Recording Dust Concentration Meter and Its Application to the Blast Furnace. A. W. Simon, L. C. Kron, C. H. Watson, and H. Raymond. Review of Scientific Instruments, Vol. 2, No. 2 (1931), page 67.

The law connecting the transmission of light and the concentration of a suspended material in a gas is deduced. It is pointed out that the Ringelmann method of measuring smoke density, as well as the so-called recording "smoke densimeters" do not measure the true *concentration* of the suspended material. The amount of light transmitted is shown to be an exponential function of the concentration. A recording instantaneous dust concentration meter making use of a thermopile as the light-sensitive element is described. Charts obtained on blast furnace gas are given.

Marking of Imported Meters. Electrical Review, Oct. 31, 1930, pages 748-749.

Report of the evidence taken at a hearing on the application of the British Electrical and Allied Manufacturers' Association for an Order-in-Council under the Merchandise Marks Oct. 1926, requiring imported meters and parts to be marked upon importation with an indication of their origin.—M. S.

Recording Dust Concentration Meter for Blast Furnace Gas. A. W. Simon. Blast Furnace and Steel Plant, Nov. 1930, pages 1686-1689, 1700.

Paper read before the American Iron and Steel Institute, Oct. 24, 1930. Describes instrument which is based on the principle that the amount of light absorbed, and therefore the amount of light transmitted, by a column of dust-laden gas depends on the dust content of the gas. One form of instrument contains a small concentrated Mazda lamp, a lens which renders the light from the filament parallel, a window in the gas-main through which the light passes into the main containing the dust-laden gas, a second window through which the light leaves the main, a second lens which concentrates the light on a thermopile, which is connected to an indicating and recording meter. The windows have motor-driven modified windshield wipers to keep them clean. Discusses theory of the instrument, describes experimental verification, and gives results obtained.—M. S.

New Sag Meter. Electrician, Vol. 105, Nov. 28, 1930, page 696.

Price & Belsham, 52 Queen Victoria St., London, E. C. 4, have introduced the "P.&B." sag meter, a surveying instrument specially designed for measuring the sag in overhead transmission lines and thereby determining the tension. It is made entirely of steel with bright parts chromium plated. The meter is made in types "A" and "B." In "A" the range is 45° above the horizontal. In "B," it is 30° above the horizontal to 15° below. Type A is intended especially for measuring in addition clearance over roads, railways, etc.—W. H. B.

An Amplifier, String Galvanometer and Photographic Camera Designed for the Study of Action Currents in Nerve. A. Forbes, H. Davis and J. H. Emerson. Review of Scientific Instruments, January 1931, pages 1-15.

Historical data are given with brief descriptions of previous attempts to obtain information about the physical nature of functional response in nerve tissue. Apparatus described is believed to be the first to record without distortion and with negligible lag the action current in nerve and particularly to furnish clear records of a single response, making possible an accurate comparison of the response in a rested nerve to a single stimulus with that evoked by the later stimuli of a rapid series. A feature of the galvanometer is a short tight gilded quartz string of about $1\ \mu$ diam., vibration frequency over 20,000 cycles.—M. F. B.

On the Plasiticity of Metals. Zay Jeffries. Mechanical Engineering, Vol. 53, April 1931, pages 262-266.

Presented at the 87th meeting of the American Association for the Advancement of Science, Cleveland, Ohio, December 31, 1930. Plasticity is defined as "the quality by virtue of which a substance may undergo a permanent change in shape without rupture." Metals are crystalline, and plastic flow is the result of the movement of one position of a crystal with reference to another along crystallographic planes. Industrial metals are useful to us because of their high plasticity without which metal-working processes could not be carried on.—M. F. B.

New Fire Control for Divisional Weapons. G. M. Wells. Army Ordnance, Vol. XI, March-April, 1931, pages 365-370.

Specialists have declared that the place of honor among instrument marvels belongs neither to the completely equipped astronomical telescope nor to the Sperry gyroscopic navigator but to the new antiaircraft fire-control instruments. These are undoubtedly deserving of respectful study by instrument designers in non-martial fields of research and application. Capt. Wells' well-illustrated paper suggests a modification of the antiaircraft set of instruments for the field artillery. The instruments are located at a remote observation post and electrically connected to the battery of four guns, on each of which are electrical receivers which automatically set the fuses and operate the azimuth and elevation directors.—M. F. B.

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Conclusion of Chap. XV of Handbook of Industrial Instruments. This installment covers:

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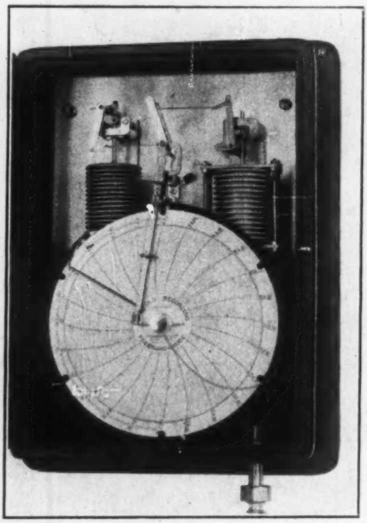

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